

ELF Communications System Ecological Monitoring Program: Final Summary Report

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<p>The U.S. Navy has completed a program that monitored biota and ecological relationships for possible effects from exposure to electromagnetic (EM) fields produced by its Extremely Low Frequency (ELF) Communications System.</p> <p>Physiological, developmental, and ecological variables for abundant biota in upland, wetland, and riverine habitats near the ELF System were monitored from 1982 and 1993. Research teams from several universities measured biological and ecological variables at about the same time at treatment and control sites, before and after the transmitting facilities became fully operational. Spatial and temporal comparisons were made using analysis of variance and intervention statistical techniques. The response of variables to natural environmental and site factors were addressed in most analyses.</p> <p>Data collection for studies located near the Naval Radio Transmitting Facility (NRTF)-Clam Lake, Wisconsin, was completed, as scheduled, during 1989. Investigators concluded that there were no effects from intermittent or full operation of the transmitter. Data collection for studies near the NRTF-Republic, Michigan, were completed during 1993. There were no unequivocal effects on the variables monitored in Michigan. A few minor changes may have occurred; however, their implication is not indicative of adverse ecological significance.</p>			
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PREFACE

This report has been prepared by IIT Research Institute (IITRI) on behalf of the Space and Naval Warfare Systems Command (SPAWAR). It summarizes the results of a Navy program monitoring for possible electromagnetic (EM) effects to biota from operation of the Extremely Low Frequency (ELF) Communications System.

Monitoring studies were performed by research teams from Michigan State University, Michigan Technological University, University of Minnesota-Duluth, University of Wisconsin-Milwaukee, and the University of Wisconsin-Parkside under subcontract agreements with IITRI. SPAWAR funded these studies through prime contracts N00039-81-C-0357, N00039-84-C-0070, N00039-88-C-0065, and N00039-93-C-0001. IITRI, a not-for-profit organization, managed the program and provided engineering support to university research teams.

The Michigan Department of Natural Resources (MDNR) supported the monitoring program by providing information for site selection and permits to conduct research on state lands. The U.S. Forest Service (USFS) provided similar help for studies conducted in the Chequamegon National Forest. The USFS, MDNR, and Wisconsin Department of Natural Resources also assisted by reviewing the program's results and progress. They continue to support these and other Navy efforts to ensure the environmental compatibility of the ELF Communications System.

The progress and development of each study was documented in a series of reports that were prepared yearly from 1982 through 1993. Over the same period, IITRI annually documented its engineering support efforts, including measurements of EM exposure at study sites. Study designs and findings have also been recounted in presentations to scientific societies, and as articles in peer-reviewed journals. The Navy provided all reports to libraries in the ELF System area, state universities, and the Library of Congress; they are also available to the public through the National Technical Information Service. Reports, publications, and presentations associated with the Ecological Monitoring Program through 1995 are listed in Appendix A. The program's design, methods, and results are currently under review by the National Research Council.

This document describes the components and operation of the ELF Communications System (Sections 1 and 2) and seeks to relate quantitative measurements of biological and ecological variables of biota residing in the ELF System area to EM exposures from operation of transmitters (Section 3). The background, description, and results of each monitoring study is presented in Sections 4 through 6 of this text. The information presented in these latter sections has been largely abstracted from final reports prepared by university research teams.

The data collected over the term of the program includes information on the structure and functioning of biotic communities commonly found in mixed northern forests, a resource commercially and culturally

important to both Canada and the United States. Besides monitoring for possible EM effects, the Navy's database is of potential use in detecting and qualifying regional changes that may occur in the future from such anthropogenic perturbations as global warming or acid rain. The database could provide lists of biota, estimates of densities, measures of spatial and temporal variability for important ecological processes and structures, as well as define the relationships between environmental factors and these variables.

Respectfully submitted,
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CONTENTS

	<u>Page</u>
Preface	v
Glossary and Acronyms	xiii
Executive Summary	xvii
1. INTRODUCTION	1
1.1 Program Purpose	1
1.2 ELF EM Communications	1
1.3 EM Effects: ELF System Research and Evaluation	1
2. ELF COMMUNICATIONS SYSTEM	5
2.1 Description	5
2.2 Signal	7
2.3 Operational History	8
2.4 EM Fields	11
3. ECOLOGICAL MONITORING PROGRAM	15
3.1 Study Sites	15
3.2 EM Exposures	18
3.3 Non-EM Environmental Factors	22
4. TERRESTRIAL STUDIES	25
4.1 Vegetation	25
4.1.1 Herbaceous Phenology and Morphology	25
4.1.2 Mycorrhizal Associations	26
4.1.3 Root Disease	27
4.1.4 Tree Physiology and Growth	27
4.1.5 Litter Production	30
4.2 Decomposition	32
4.2.1 Litter Breakdown	32
4.2.2 Earthworm Biology and Ecology	34
4.2.3 Surface-Active Arthropod Behavior	36
4.2.4 Soil and Litter Arthropod Ecology	37
4.2.5 Streptomyces Ecology	38
4.2.6 Amoebae Biology and Ecology	39
4.2.7 Slime Mold Physiology	41
4.3 Permeants	44

CONTENTS (continued)

	<u>Page</u>
4.3.1 Bee Behavior and Ecology	44
Foraging Activity	45
Nest Architecture	46
Mortality	47
4.3.2 Bird Behavior, Biology, and Ecology	49
Embryology	49
Fecundity, Growth, and Development	50
Physiology	52
Homing	53
Mortality	55
Populations and Communities	55
4.3.3 Mammal Behavior, Biology, and Ecology	58
Growth and Development	58
Physiology	59
Homing	60
5. WETLAND STUDIES	61
5.1 Vegetation: Herb, Shrub, and Tree Physiology	61
5.2 Decomposition: Litter and Cellulose Breakdown	62
6. FRESHWATER STUDIES	65
6.1 Producers: Periphyton Ecology	65
6.2 Primary and Secondary Consumers	68
6.2.1 Benthic Insect Ecology	68
6.2.2 Leaf-pack Insect Ecology	69
6.2.3 Naiad Movement Behavior	71
6.3 Tertiary Consumers	71
6.3.1 Fish Ecology	72
6.3.2 Fish Movement Behavior	73
7. REFERENCES	75

APPENDIXES

- A. List of Program Publications and Presentations (1982-1995)
- B. Statement of Work and Program Summary (1982-1995)
- C. Voltage Spectra: South Antenna NRTF-Clam Lake
- D. Non-EM Environmental Factors Monitored at ELF Ecology Sites

FIGURES

<u>Figure</u>	<u>Page</u>
1 ELF Communications Facilities in Michigan and Wisconsin	2
2 Transmitting Facility: NRTF-Republic, Michigan	5
3 Overhead Antenna: NRTF-Republic, Michigan	5
4 ELF Modulated Waveform and Power Spectral Distribution	7
5 Duration of EMF Exposure at the NRTF-Clam Lake (1984-1989)	9
6 Duration of EMF Exposure at the NRTF-Republic (1986-1993)	10
7 Magnetic and Earth Electric Fields Generated by the Transmitting Antenna	12
8 Earth Electric Field from Buried Grounding Wire	12
9 Air Electric Field from Transmitting Antenna	13
10 ELF Ecological Study Sites in Michigan	17
11 ELF Ecological Study Sites in Wisconsin	18
12 76 Hz Magnetic Field Exposure at Wisconsin Study Sites (1985-1989)	21
13 76 Hz Magnetic Field Exposure at Michigan Study Sites (1989-1993)	21
14 76 Hz Earth Electric Field Exposure at Wisconsin Study Sites (1985-1989)	21
15 76 Hz Earth Electric Field Exposure at Michigan Study Sites (1989-1993)	21
16 Deviation of Cumulative Water Temperatures in the Ford River, Michigan (1983-1988)	23
17 Deviation of Cumulative Water Temperatures in the Ford River, Michigan (1989-1993)	23
18 Deviation of Monthly Precipitation at Iron Mountain, Michigan (1984-1993)	24
19 Estimated Effect of ELF Magnetic Field Exposure on the Diameter Growth of Aspen Trees	29
20 Annual Decomposition of Maple, Pine, and Oak Leaf Litter in Hardwood Stands	33
21 Maple Leaf Decomposition in Litter Bags Relative to Litter-Feeding Earthworms	34
22 Annual Diversity of the Earthworm Community at ELF Sites in Michigan	35
23 Number of Amoebae in Upper Soil Horizons	41
24 Respiration Rates of Laboratory Grown Macroplasmodia	42
25 Respiration Rates of Macroplasmodia Grown Near the NRTF-Clam Lake	43
26 Cutaway view of Trap Nests Completed by <i>Megachile inermis</i> and <i>M. inermis</i>	45
27 Overwinter Mortality of <i>Megachile inermis</i> Prepupae (1987-1992)	48
28 Overwinter Mortality of <i>Megachile inermis</i> Prepupae in Transferred and Untransferred Nests (1991-1992)	48
29 Tree Swallow Mass Growth Constants (1985-1991)	51

FIGURES (continued)

<u>Figure</u>		<u>Page</u>
30	Tree Swallow Age at Eye Opening (1986-1991)	52
31	Return Routes for Displaced Tree Swallows	53
32	Return Speeds of Displaced Tree Swallows	54
33	Number of Birds and Bird Species Observed in Michigan during Spring Migration (1986-1993)	57
34	Number of Birds and Bird Species Observed in Michigan During Breeding Periods (1986-1993)	57
35	Deermouse Mass Growth Constants (1986-1991)	59
36	Deermouse Age of Eye Opening (1986-1991)	59
37	Annual Decomposition of Labrador Tea Foliage in Wisconsin Peat Bogs (1985-1987)	63
38	Species Diversity of Diatoms in the Headwaters of the Ford River, Michigan (1984-1993)	66
39	Chlorophyll Biomass in the Headwaters of the Ford River, Michigan (1984-1993)	67
40	Relationship of Insect Mass to EM and Non-EM Site Factors During Michigan Summers (1984-1993)	69
41	Average Annual Insect Mass Relative to Leaf Mass After Four Weeks Emplacement in the Ford River, Michigan (1984-1992)	70
42	Relative Biomass of Dominant Fish in the Ford River, Michigan (1983-1993)	72

TABLES

<u>Table</u>		<u>Page</u>
1	Structural and Electrical Characteristics of the ELF Communications System at Full Operational Capability	6
2	Operational Characteristics of the NRTF-Clam Lake During Ecological Monitoring (1984-1989)	9
3	Operational Characteristics of the NRTF-Republic During Ecological Monitoring (1983-1993)	10
4	Treatment and Control EM Relationships for ELF Environmental Studies	16
5	Relationship of Ecological Study Sites to the ELF Communications System	19
6	Comparison of Treatment and Control Results for <i>Appoectodea tuberculata</i> Grown in Mesh Bags	36

GLOSSARY AND ACRONYMS

AFDW	ash free dry weight, used as a measure of biomass.
AIBS	American Institute of Biological Sciences.
ANOVA	analysis of variance, a statistical technique for partitioning the total variability affecting a set of observations between the possible and statistically independent causes of the variability.
ANCOVA	analysis of covariance, a statistical method for determining whether the functional relationships described by two or more regression equations are the same; it is used when treatments are compared in the presence of accompanying variables that cannot be eliminated or regulated.
BACI	before and after, control and impact, a statistical technique which compares the mean of the "before" differences between the control and treatment(impact) sites to the mean of the site differences "after" the treatment (i.e., full transmitter operation).
biomass	quantitative estimate of the total mass of living organisms comprising all or part of a specified unit such as a population.
CATMOD	categorical data modeling, a statistical procedure used to compare proportions.
chi-square	a statistical method for testing the degree to which observed frequencies or values differ from frequencies or values expected from the specific hypothesis being tested.
chlorophyll	a photosynthetic pigment reflecting green light; in the aquatic studies it is used as a measure of plant productivity or standing crop.
clone	an assemblage of genetically identical organisms derived by a sexual or vegetative multiplication from a single sexually derived individual.
control	a location where parallel observations or experiments are carried out; they provide a standard against which a result can be compared. As used in this report, it is a location remote from the ELF Communications System, having 76 Hz EM intensities at least one order of magnitude less than its matched treatment site.
detection limit	the degree of difference which leads to a 50 percent chance of correctly rejecting the null hypothesis for a given alpha level.
diatoms	a group of algae that often dominate aquatic communities in unpolluted rivers.
edge effect	the impact exerted by adjoining communities on the population structure within the marginal zone which often contains a greater number of species and higher population density of some species than either adjoining community.
ELF	extremely low frequency; in general use, refers to frequencies ranging from 0 to 300 Hz; as used in this report, refers to operating frequencies of Navy's ELF Communications System (i.e., 76 ± 4 Hz).

EM	electromagnetic, pertaining to the effects of both electric fields and magnetic flux densities.
EW	refers to antennal elements oriented in an east/west direction.
fecundity	the potential reproductive capacity of an organism or population, measured by the number of gametes.
FOC	full operational capability, refers to characteristics of the ELF System when broadcasting messages.
genet	a unit or group of organisms derived by asexual reproduction from a single, original fertilized cell.
genetic heterogeneity	a measure of the genotypic disparity within a population, the different forms of a gene occupying the same locus or loci.
GLM	general linear model, a statistical procedure used when values are weighted by their rank in a sequence.
guild	a group of species having similar ecological resource requirements and foraging strategies, and therefore having similar roles in the community.
herbaceous plants	plants which have stems that are not secondarily thickened or lignified and which die down annually.
Hz	hertz, a measure of frequency in cycles per second.
IITRI	IIT Research Institute
IEEE	Institute of Electronic and Electrical Engineers.
kV/m	kilovolts per meter.
litter	either recently fallen plant material that is only partially decomposed and in which the organs of the plant are still discernible, forming the surface layer on some soils, or those animals produced at a multiple birth.
macro-plasmodium	a large multinucleate mass of slime mold protoplasm visible to the eye; in the laboratory or fields it is maintained on a solid substrate such as agar.
magnetic flux density	A vector quantity describing the magnetic force exerted on a moving unit charge at a given point in space.
MDNR	Michigan Department of Natural Resources.
mG	milligauss, a measure of magnetic flux density, equivalent to 0.1 microtesla (μ T).
micro-plasmodium	a small multinucleate mass of slime mold protoplasm not visible to the eye; in the laboratory it is maintained in submerged liquid culture.
MSU	Michigan State University.
MTU	Michigan Technological University.
mV/m	millivolt per meter, used as a measure of electrical field intensity in soil or water.

mycorrhiza	a mutually beneficial association between plant roots and certain highly specialized fungi.
NANOVA	nested analysis of variance.
NAS	National Academy of Sciences.
NIST	National Institute of Standards and Technology.
NRTF	Naval Radio Transmitting Facility.
NS	refers to antennal elements oriented in a north/south direction.
parameter	a characteristic of the distribution of a variable or population, such as the mean.
periphyton	a community of plants, animals, and associated detritus adhering to and forming a coating on submerged objects.
phenology	the study of temporal aspects of recurrent natural phenomena, e.g., flowering.
regression analysis	in statistics, the estimation of the relationship between one variable and one or more other variables, by expressing one in terms of a linear or more complex function of the others.
RIA	randomized intervention analysis, a nonparametric statistical procedure in which the test statistic is compared to a random distribution of the data set, equivalent to BACI.
ROW	right-of-way, cleared corridor for location of antenna elements.
sham ROW	a cleared corridor located on control sites which is used to duplicate possible effects from the antenna ROW on study variables.
significance	the probability (p) that experimental results have not occurred by chance alone; in these studies p < 0.05.
SPAWAR	Space and Naval Warfare Systems Command.
species evenness	the apportionment of individuals among those species found in a given community.
species diversity	a measure of the number of species and their relative abundance in a community.
species richness	the absolute number of species in an assemblage or community.
statistical power	the likelihood that a particular statistical test of a variable parameter will lead to rejecting the null hypothesis if the hypothesis is false.
t-test	a statistical method used for determining the significance of the difference between two means when the samples are small and drawn from a normally distributed population.
treatment	a location where primary observations or experiments are carried out and where biota are site exposed to 76 or 44 Hz EM intensities at least one order of magnitude greater than its matched control site.

UMD	University of Minnesota-Duluth.
UWM	University of Wisconsin-Milwaukee.
USFS	United States Forest Service.
UWP	University of Wisconsin-Parkside.
variable	a property with respect to which individuals within a sample differ in some discernible way.
WTF	Wisconsin Test Facility.

EXECUTIVE SUMMARY

The U.S. Navy's Extremely Low Frequency (ELF) Communications System currently provides reliable communication to submarines without the risk of detection commensurate with their rising to the surface. Concomitant with its construction in 1981, the Navy implemented studies to examine for possible effects on biota from exposure to electromagnetic fields (EM) produced by the ELF System. Studies were completed and all results documented during 1994 and 1995. This report provides background information and reviews the results of biological and ecological monitoring studies.

The ELF System consists of two transmitting facilities, one in north central Wisconsin and the other on the Upper Peninsula of Michigan, that synchronously broadcast messages using frequency-modulated signals centered at 76 Hz. The transmitters became fully operational during 1985 and 1989 in Wisconsin and Michigan, respectively. The transmitters use loop antennas formed by long wires grounded in an earth return configuration to produce the desired signals. Magnetic flux densities and earth electric field intensities near the transmitting antennas are comparable to intensities experienced near electric power transmission lines. Air electric field intensities produced by the ELF System are at least two orders of magnitude lower than found in transmission line environments.

Research teams from several universities measured biological and ecological variables at treatment and control sites, before and after the transmitting facilities became fully operational. Treatment sites were located close to transmitting antennas and ground terminals. Control sites were located at such a distance that EM exposures were at least one order of magnitude less than those experienced at treatment sites. Investigators monitored over 335 variables on the behavior, physiology, development, and ecology of abundant biota residing at terrestrial, wetland, and aquatic study sites. Spatial and temporal comparisons of parameters were commonly made using analysis of variance and intervention statistical techniques. The response of variables to natural environmental and site factors were addressed in most analyses.

Terrestrial and Wetland Vegetation

Studies of upland vegetation (herb and tree species) found no connection of ELF EM exposure with the timing of important events (e.g., flowering, fruiting, leaf fall), spread of disease, leaf water potential, or foliar nutrient concentrations. Similar results were obtained for the leaf water potential and foliar nutrient content of four wetland plants (tree, shrubs, and herb). Findings indicated no stress to short- or long-lived plant species. Water potential and nutrient results further suggest that EM intensities produced by a fully operational ELF System did not interfere with overall water or nutrient uptake across plant cell membranes.

Results from studies of upland forest productivity yielded indefinite results. Three of five tree species showed a statistical association between enhanced growth and magnetic field exposures from one to seven mG. Seasonal patterns of tree growth and leaf litter production, another measure of productivity, exhibited

no link to ELF EM exposure. Although researchers did not claim a causal relationship between magnetic field exposure and increased tree growth, they did conclude a strong association.

Terrestrial and Wetland Decomposition

An ELF EM exposure influence on individuals or the structure of the macrobiotic, mesobiotic, or microbiotic communities in the litter and soil was not evident at upland sites. Changes in the genetic heterogeneity, mitotic cycle, growth, or respiration of amoebae and slime molds were not detected when these "naked cells" were closely coupled to ELF electric fields produced in the soil. Earthworm population characteristics were also closely examined as they play an important litter-decomposition role in some upland habitats. Investigators believe that there may have been a short-term reproductive effect due to exposure in one worm species. They conclude, however, that there were no lasting effects to the physiology, behavior, development, or population biology of this or other worm species from a fully operational transmitter.

The overall functioning of the soil community was evaluated by monitoring rates of litter decomposition. Results were mixed. Studies by one research team did not reveal any effect of EM exposure on the decomposition of sugar maple foliage, while another team found a temporary increase in the decomposition of EM-exposed red maple, oak, and pine foliage at hardwood stands, but not at sites planted with pine trees. If valid, positive results would be consistent with a transitory EM effect smaller than naturally occurring year-to-year fluctuations.

In a similar study, the decomposition of shrub leaves and cellulose pads were monitored in peat bogs. Initial statistical testing examined seven study periods for differences from four exposure regimes. During one of the periods, decomposition was significantly faster at the antenna (but not the ground terminal or intermediate) sites than at the controls. Further testing using regression techniques showed no relationship between decomposition rates and EM exposure. Investigators concluded that operation of the Wisconsin transmitter had no measurable effects on litter decomposition in bogs.

Permeants (Highly Mobile Animals)

Two native bee species were monitored as representative pollinators. The overall pattern of results did not exhibit disorientation, stress, or reduced parental investment in offspring. Of fourteen variables monitored, two significant differences (leaves per reproductive nest cell and overwintering mortality for one species) indicated a relationship to ELF EM exposure. In both cases, differences at exposed and unexposed sites were significant prior to full operation of the Michigan transmitter. Site values converged, and there were no significant differences under full operational conditions. Inferences drawn from these findings are limited by the small sample sizes at the control site during the preoperational period, and an absence of climatological data at overwintering sites. Investigators conclude that a few minor changes in nest architecture and bee mortality may have occurred after the Michigan transmitter became fully operational; however, differences were small and inconsistent across time and species.

The ecology of the bird communities in habitats near both the Wisconsin and Michigan transmitters were studied. In addition, two species of small birds (one permanent resident and one breeding migrant) were monitored as representative vertebrates. The embryology; postnatal growth and development; adult health, homing, and fecundity; and mortality of life cycle stages of the bird species were examined by investigators. They concluded that study results did not demonstrate any ELF EM effects on adults, young, or the bird community as a whole.

Investigators also examined the postnatal growth and development, homing of adults, and health of two mammals (deer mouse and chipmunk). There was no pattern of EM effects on nestling growth, adult health, or homing. The developmental marker, age at eye opening, changed little for mice at the treatment site, while at the control site it increased steadily over the term of the study. Investigators consider that this statistically significant interaction could be related to ELF EM exposure, but they could not infer if the putative relationship was detrimental. Age at incisor eruption, a marker that appears later in development, and overall growth rates of nestlings did not show an association with EM exposure.

Wildlife surveys concurrently performed by the U.S. Forest Service (USFS) showed that ruffed grouse, eagle, and deer population sizes near the Wisconsin transmitter were similar to statewide averages. These results are consistent with ELF program findings and indicate no measurable, adverse effects on avian or mammalian wildlife from ELF EM exposure.

Aquatic Biota

Three communities (periphyton, insect, and fish) comprising the major trophic levels of the Ford River were monitored for changes in their structural and functional characteristics. Although some comparisons were significant (including several productivity variables), additional statistical testing did not confirm the initial results. In nearly all cases, the variability within parameters was primarily associated with natural environmental conditions and not EM exposure. The overall pattern of results was not consistent with exposure milestones in ELF System operation. Investigators found that fish moved both upstream and downstream beneath an energized transmitting antenna, and the movement of dragonfly naiads was unaffected. They concluded that operation of the Michigan transmitter had no effects on the ecology or behavior of biota in the Ford River.

Overall Summary and Conclusions

In each of the program's eleven studies, initial statistical testing resulted in some significant results. The number of significant results was small and not greater than expected to occur by chance alone. Generally, none of the initially significant results were corroborated when further examined by supplemental experiments or additional statistical analyses. Regressions and correlations used in supplemental analyses indicated that biological and ecological variables were markedly more sensitive to physicochemical and biotic factors than EM exposure when the variables were related to exposure at all.

The investigators consider results for tree growth, postnatal development in deermice, bee mortality and nest architecture, and litter decomposition as having shown some association with ELF EM exposure.

They note, however, that inferences would be limited by the absence of comparable results across species or related variables (e.g., age of eye opening versus other developmental variables), and in some cases, by the small difference between treatment and control values.

Although some investigators believe that a few biological changes may have occurred, all acknowledge that there were no consistent, unequivocal effects of ELF System operation on any of the variables they monitored. All conclude that the implications of their results are not indicative of adverse ecological significance.

EXTREMELY LOW FREQUENCY (ELF) COMMUNICATIONS SYSTEM ECOLOGICAL MONITORING PROGRAM: FINAL SUMMARY REPORT

1. INTRODUCTION

1.1 Program Purpose

The purpose of the Ecological Monitoring Program was to determine whether electromagnetic (EM) fields produced by the Navy's ELF Communications System affected resident biota or their ecological relationships.

1.2 ELF EM Communications

EM energy at ELF wavelengths both propagates over large distances with little attenuation, and can penetrate deeply into seawater. Propagation of an ELF signal in the space between the earth's surface and the ionosphere is also minimally affected by natural and man-made disturbances. These ELF attributes permit reliable, long-distance communication with submarines without the risk of detection by their rising to the surface to receive messages.

The Department of the Navy first became interested in using ELF EM signals to communicate with submerged submarines in the late 1950s. Subsequently, they conducted studies to verify theoretical predictions and provide a basis for design parameters at several sites within the United States. Site Alpha was a temporary experimental antenna constructed in North Carolina/Virginia (Site Alpha) during the early 1960s. Later in 1969 the more substantial Wisconsin Test Facility (WTF) was built near Clam Lake in northern Wisconsin. Site Alpha was periodically used from 1963 until 1969; it no longer exists [1,2]. The WTF was in use from 1969 until 1979 when the ELF Communications Project was temporally halted.

In 1981, the President directed the Navy to proceed with its program for constructing a fully functional (now named) ELF Communications System. The WTF was upgraded and became fully operational in 1985. Construction of a second transmitter near Republic, Michigan, was initiated in 1983. Intermittent operation of the Michigan transmitter began in 1986, and it became a fully operational facility in 1989. The WTF is now designated as the Naval Radio Transmitting Facility (NRTF)-Clam Lake, and the facility in Michigan as the NRTF-Republic (Figure 1).

1.3 EM Effects: ELF System Research and Evaluations

A literature review of the potential biological effects that might result from operating the then-proposed underground ELF communications system (Project Sanguine) was conducted in 1967 and 1968. The review found the scientific literature insufficient to allow definitive conclusions on EM effects, and in

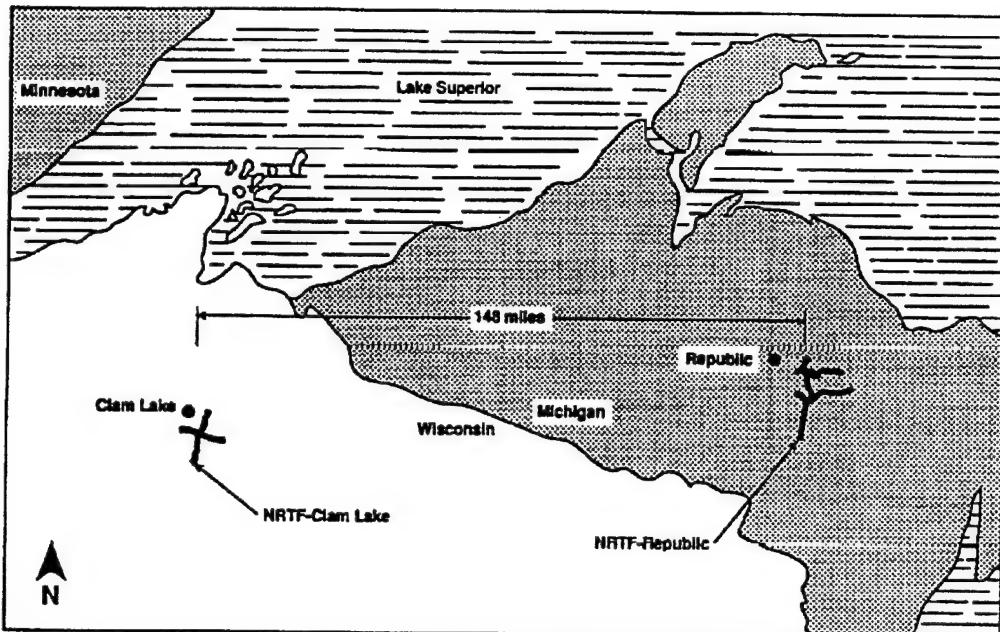


FIGURE 5. ELF COMMUNICATIONS FACILITIES IN MICHIGAN AND WISCONSIN.

1969, the Navy initiated research to determine whether biological or ecological effects occurred from EM exposure to fields from a Sanguine ELF antenna.

Although some ecological and wildlife studies were performed at Site Alpha and the WTF, most of the early, ELF system-related research was simulated in laboratories [3]. Both types of studies were performed through 1977 when the Navy [4] and the National Academy of Sciences (NAS) [5] examined the information produced by these, as well as other studies performed at different ELF frequencies (mainly 60 Hz). Based on their review the Navy and the NAS each concluded that adverse effects to biota from operation of a buried grid of ELF antennas (Project Seafarer) were unlikely. Despite the unlikelihood of EM bio effects, the Navy and NAS recommended *in situ* monitoring of biota if an ELF system was built.

Based on their review of bioelectromagnetic research published over the 1977-1984 period, the American Institute of Biological Sciences (AIBS) [6] later concurred with the earlier Navy and NAS conclusions. The AIBS noted that most results reported in the literature could not be extrapolated to the natural complexity of habitats in the ELF system area. They advised the Navy to continue ongoing *in situ* research in order to verify predictions of low risk to biota.

The Navy had outlined a preliminary plan for conducting a monitoring program at those sites approved for operation of an ELF communications system in its final environmental impact statement [4]. The plan was further developed using comments on the draft environmental impact statement, as well as inputs from the NAS, state agencies, U.S. Forest Service, and others [7]. Following approval to complete construction of the

ELF system, technical elements of the plan were consolidated into a statement of work that was later issued with a request for proposals.

In 1982, the Navy established an Environmental Review Committee (ERC) to oversee environmental matters pertaining to ELF Communications System and to ensure coordination with the state governments of Wisconsin and Michigan, and the U.S. Forest Service. With regard to the Ecological Monitoring Program, the ERC adopted an approach of peer review as a basis for technical management and open reporting by investigators. This was done to insure the scientific and public credibility of the program's findings.

In order to acquire pertinent monitoring proposals and the most qualified research teams, IITRI conducted a competitive proposal procurement on behalf of the Navy. Over 120 proposals were received and evaluated for merit. Technical evaluations were performed by recognized scientific experts with established research experience in the topics they critiqued. Reviewers were selected independent of Navy approval or recommendation. None of the reviewers were under contract or grant award by the Navy, nor were they associated with organizations proposing ELF ecological studies. Eleven research teams were eventually selected to perform the studies. Nine began their work by mid-1982, while two others began later, one in 1983 and one in 1984 (see Appendix B). Early efforts focused on the selection of study sites, validation of assumptions made in the proposals, and characterization of critical study aspects. After these tasks were accomplished in 1984 and 1985, increased emphasis was then placed on data collection and analyses. Data collection for studies located near the NRTF-Clam Lake and those near the NRTF-Republic were completed, as scheduled, during 1989 and 1993, respectively. All results had been documented by 1995.

The development and progress of each study was documented on an annual basis in reports by research teams. Each report was peer reviewed, and submitted (unedited by the Navy or IITRI) to the National Technical Information Service for unlimited distribution. In addition, the Navy encouraged and supported researcher presentations to scientific societies and articles in peer-reviewed journals (Appendix A). The program's design, methods, and results are currently under review by the National Research Council's Board on Environmental Studies and Toxicology in collaboration with the Board on Radiation Effects Research.

Concomitant with ELF monitoring studies, the U.S. Forest Service independently performed wildlife surveys in the Chequamegon National Forest near the NRTF-Clam Lake. Annual surveys of ruffed grouse, eagle, and deer populations were initiated in 1974, 1975, and 1982, respectively. Although not examined on a statistical basis, results did not indicate any effects to these populations from the operation of the ELF Communications System, and the studies were concluded after the 1986 surveys. Study results were reported annually to the Navy's Environmental Review Committee. Protocols and data are summarized in Appendix B of Reference 8.

2. ELF COMMUNICATIONS SYSTEM

2.1 Description

The ELF Communications System consists of two facilities, one in north central Wisconsin (NRTF-Clam Lake) and the other on the Upper Peninsula of Michigan (NRTF-Republic). Each facility consists of a transmitter (Figure 2), pole-mounted antenna cables (Figure 3), and buried ground terminals. The transmitter sends an electrical current through the antenna cables into the earth at the ground terminals. The current then flows back to the transmitter through the earth, thus completing the circuit. Most of the earth return current flows deeply, and disperses throughout the bedrock underlying the ELF system area.

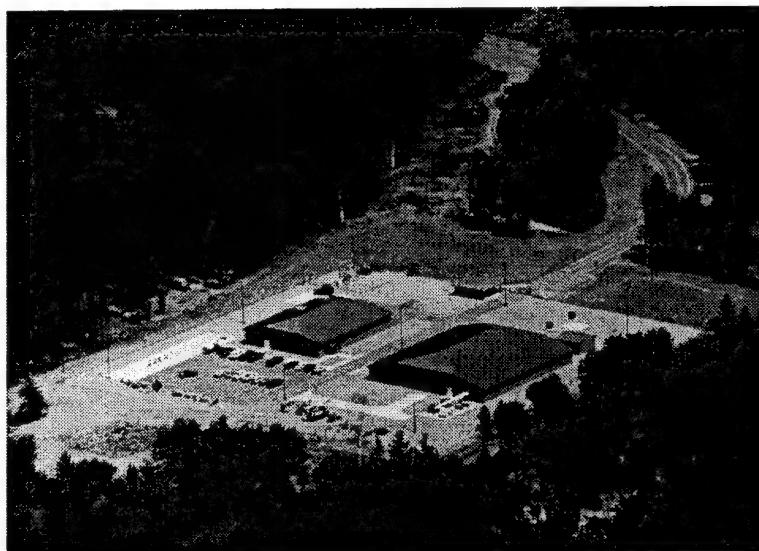


FIGURE 2. TRANSMITTING FACILITY: NRTF-REPUBLIC, MICHIGAN.



FIGURE 3. OVERHEAD ANTENNA: NRTF-REPUBLIC, MICHIGAN.

The NRTF-Clam Lake has two orthogonal antennas, one essentially oriented north-south (NS) and the other east-west (EW) (Figure 1). Each antenna is 14 miles long and carries 300 amperes of current (Table 1). The NRTF-Republic has one NS antenna and two EW antenna elements. The total length of the antennas is 56 miles, and each carries 150 amperes of current. The antennas consist of two conductors in Wisconsin and a single conductor in Michigan; they are suspended about 40 feet above ground by wood utility poles.

**TABLE 1. STRUCTURAL AND ELECTRICAL CHARACTERISTICS
OF THE ELF COMMUNICATIONS SYSTEM
AT FULL OPERATIONAL CAPABILITY**

Characteristics	NRTF-Clam Lake Wisconsin	NRTF-Republic Michigan
Antennas		
Numbers/length (miles)	1 NS/14, 1 EW/14	1 NS/28, 2 EW/14
Aerial cables	2	1
Ground Terminals		
Number	4	6
Buried cable (miles)	10	11
Wells	17	44
Transmitters		
Full operation (yr)	1985	1989
Current (A)	300	150
Voltage (kV)	< 4.8	< 4.8

All antenna currents enter the earth through ground terminals. Terminal designs vary according to local geology and employ one to four miles of bare wire buried 6 to 8 feet deep, as well as arrays of vertical electrodes (well grounds) extending to depths of 100 to 300 feet. At the Wisconsin ground terminal, 36 percent of all current is fed from well grounds and 64 percent from buried ground wires. In Michigan approximately half of all current enters the earth through well grounds and half through horizontal grounds. These numbers are likely to change as it is anticipated that the number of well grounds will be increased in both Wisconsin and Michigan in association with long-term facility improvements planned for both sites.

Both the antenna and ground terminals are located in cleared rights-of-way (ROWS) that are 70-100 feet wide. A transmitter is located near the intersection of the NS and EW antennas in each state. The transmitters have been operated either synchronously or independently to broadcast messages.

2.2 Signal

The ELF Communications System uses a frequency modulation principle called minimum-shift keying. In this type of modulation, the signal consists of smoothly connected segments of sinusoidal signals of two distinct frequencies (Figure 4). In this case, the frequency is shifted between 72 Hz and 80 Hz (a center frequency of 76 Hz) depending on whether an analogous binary code of "one" or "zero" is to be transmitted. Transitions from one frequency to the other occur at the peak or zero crossings of a wave in order to minimize the signals bandwidth or frequency spectra. Frequency components outside of the shift frequency band are also attenuated through the use of filtering at the transmitter outputs.

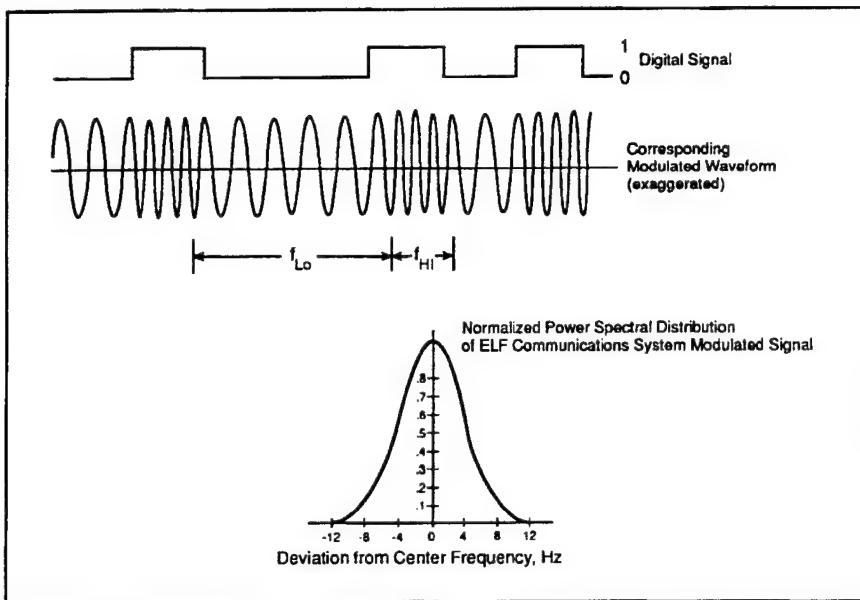


FIGURE 4. ELF MODULATED WAVEFORM AND POWER SPECTRAL DISTRIBUTION.

The frequency spectra (0-1000 Hz) produced by the fully operational ELF System, as well as the spectra produced by EM coupling from the electric power distribution, were measured at the NRTF-Clam Lake (for examples, see Appendix C). Similar measurements were not made at ecological sites; however, the relative distribution of those frequencies produced by the ELF System operation remains the same for the magnetic and air electric field (but not the earth electric field) regardless of the measurement locations. During annual EM field measurements at the ecology sites, it was standard practice to periodically perform a scan of the frequency band from 20 to 1000 Hz. Occasionally a relatively high amplitude harmonic of 60 Hz was encountered; otherwise, the spectral distribution was as expected for the antenna and power distribution systems.

In both Wisconsin and Michigan, ELF antenna currents were incrementally increased and were held constant at set amperages over a given period. Unlike electric power distribution, the ELF System does not produce transient spikes in current. "On-off" cycling was generally greater during testing periods than during full operation of the transmitters. Energizing and deenergizing of antennas were done over a period of several minutes. As such, neither normal operations nor "on-off" cycling would have produced biological effects similar to those reported when conductors are rapidly energized over millisecond or smaller intervals (pulsing).

2.3 Operational History

Prior to reaching full operational capability (FOC), both ELF transmitters were intermittently operated at lower than planned power levels in order to accommodate safety testing and other engineering needs. It is estimated that the ELF System could operate in the present FOC configuration for another 30 years. Although the primary focus of each monitoring study was the period of full operation, biological and ecological data was also collected under several other ELF System conditions. Consistent with present ELF EM research interests of the scientific community, the magnitude of the magnetic field due to current flow on the antenna and the duration of exposure, antenna "on" time, were considered the most important operational characteristics of the transmitters. Waveforms and "on-off" cycles help to define FOC and could also be important exposure factors in themselves.

After the WTF was constructed in 1969, it was intermittently operated under a variety of configurations over the next 15 years. It was operated in this manner in order to develop methods for preventing EM interference on public utilities, conduct propagation tests, and make engineering evaluations of equipment. In 1984 monitoring studies began to collect data (Appendix B). New transmitters were installed during winter 1984-85, and FOC was reached in October 1985. Data collection at ecological study sites near the NRTF-Clam Lake then continued through 1989.

At FOC, antennas in Wisconsin were energized at 300 amperes broadcasting messages using a signal modulated between 72 and 80 Hz. Less than continuous operation was scheduled in order to accommodate routine maintenance of the facility. Occasionally, a transmitter was off over longer than scheduled intervals due to equipment failure or special testing (July-August 1989) (Figure 5). As a result, the duration of EM exposures at study sites during FOC ranged from 72 to 96 percent of the available time (Table 2).

In Michigan, construction of an ELF transmitter facility began in 1983 and was completed in March 1986 when intermittent, low-power testing began (Table 3). Low-power testing at progressively higher antenna currents continued through April 1989, after which intermittent full-power procedures were followed. The antennas were operated in the intermittent configuration to conduct testing of the system and to take measurements of coupled interference on public utilities. The NRTF-Republic became a fully operational facility in early October 1989. Data on most ecological monitoring variables were being collected at the start of the 1984 field season, and continued to be compiled through the end of the field season in October 1993.

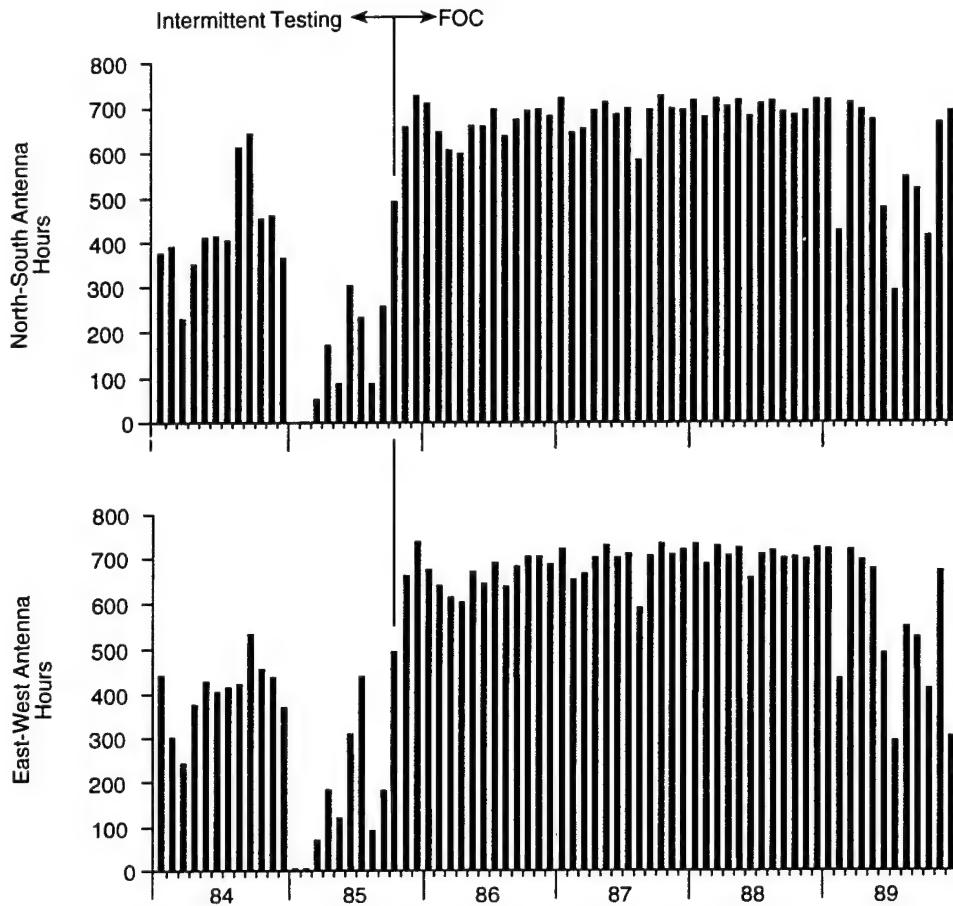


FIGURE 5. DURATION OF EMF EXPOSURE AT THE NRTF-CLAM LAKE (1984-1989).

TABLE 2. OPERATIONAL CHARACTERISTICS OF THE NRTF-CLAM LAKE DURING *IN SITU* DATA COLLECTION (1984-1989)

Activity	Antenna Current (A)	"On" Time (%)	Wave-form	"On-Off" Cycles (No.)	Time Period (mo/yr)
Testing	290	57	M	2280	01/84-12/84
	290	20	M	874	01/85-09/85
FOC	300	85	M	152	10/85-12/85
	300	90	M	1012	01/86-12/86
	300	94	M	298	01/87-12/87
	300	96	M	287	01/88-12/88
	300	72	M	504	01/89-12/89

"On" times and "on-off" cycles are presented as averages of NS and EW antennas.
M = modulated; FOC = full operational capability.

TABLE 3. OPERATIONAL CHARACTERISTICS OF THE NRTF-REPUBLIC DURING *IN SITU* DATA COLLECTION (1983-1993)

Activity	Antenna Current (A)	"On" Time (%)	Wave-form	"On-Off" Cycles (No.)	Time Period (mo/yr)
Construction	-	-	-	-	11/83-02/86
Testing	4-10	<2	CW	223	03/86-10/86
	-	-	-	-	11/86-03/87
	15	<4	CW	4829	04/87-06/88
	75	6	CW & M	5068	07/88-04/89
	150	70	CW & M	780	05/89-09/89
FOC	150	99	M	215	10/89-12/89
	150	91	M	532	01/90-12/90
	150	80	M	380	01/91-12/91
	150	77	M	192	01/92-12/92
	150	93	M	158	01/93-10/93

"On" times and "on-off" cycles are presented as averages of NS and EW antennas.

M = modulated; CW = single frequency; FOC = full operational capability.

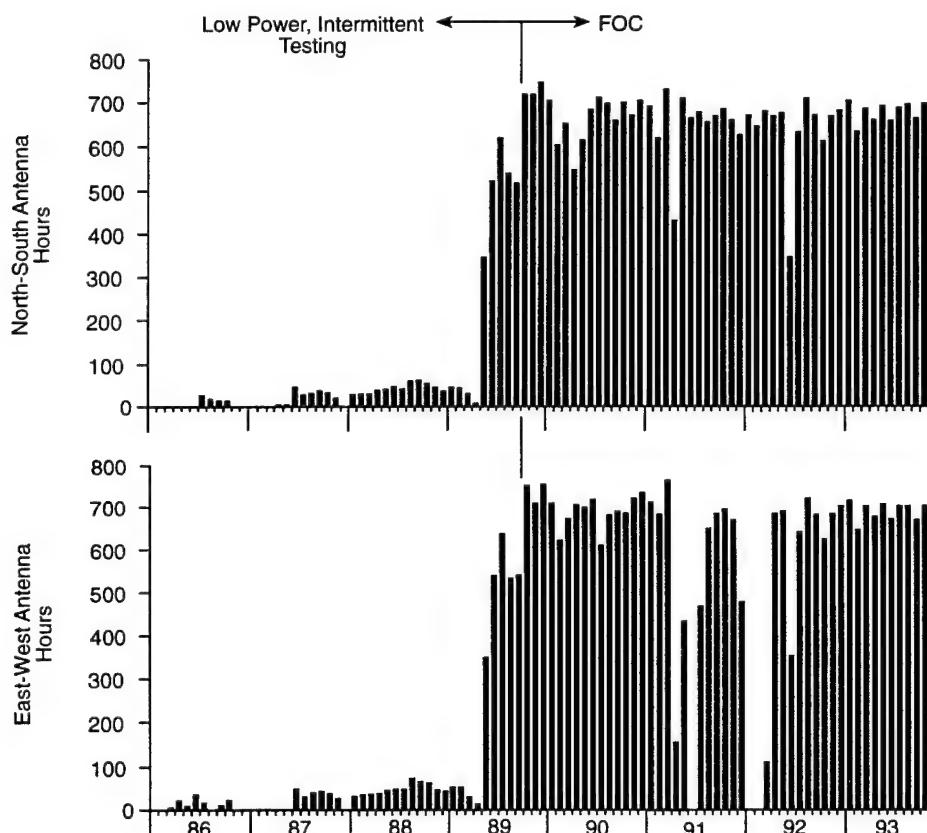


FIGURE 6. DURATION OF EMF EXPOSURE AT THE NRTF-REPUBLIC (1986-1993).

As planned, Michigan antennas were energized at 150 amperes at the same modulated frequency used in Wisconsin. System testing and equipment failures were also experienced during its FOC, resulting in annual exposure durations of 77-99 percent of the available time (Figure 6). Note that the exposure durations experienced by study sites along the EW antenna during 1991 and 1992 were shorter than the exposures experienced along the north-south antenna.

The continuity of exposure duration during ecological monitoring was quite variable, particularly during testing at the NRTF-Republic. During these times, EM exposures were limited to periodic but brief periods during workdays only. The antennas were not energized on weekends or from dusk to dawn on workdays. As the facility approached FOC, EM exposures became longer and more continuous (see Reference 10).

2.4 EM Fields

When energized, an ELF transmitter facility produces: a magnetic field, an electric field in the earth (Figures 7 and 8), and an electric field in the air (Figure 9). The current on antenna wires causes the magnetic field (B). The magnetic field induces an electric field in the earth (E_{e1}). The injection of electrical currents into the earth at ground terminals results in secondary, more localized, conductive electric fields in the soil (E_{e2}). Finally, an electric field in air (E_a) is caused by the voltage difference between the aerial antenna wire and the earth. The fields produced by the ELF facility are similar to, and are subject to the same factors, as the EM fields produced by electric power transmission or distribution lines.

Magnetic fields are the least variable of all the EM fields produced by the ELF System. Flux density at study sites is dependent on the relative magnetic permeability (μ_r) of intervening media, the antenna current, and the distance of the measurement point from the antenna (h,x) (Equation 1). Magnetic flux density is not, however, dependent on weather or other seasonal changes except to the extent that wire height (sag) is slightly dependent on temperature. The relative magnetic permeability of nonferrous materials such as air, soil, water, and biological tissue is generally of unit magnitude. Although antenna currents were changed incrementally over time, they remained uniform over any given increment or operational period (Tables 2 and 3). As such, measured values were highly consistent within operational periods and intensities could be confidently extrapolated across space and time.

Electric fields in the earth are more variable than magnetic fields. This is because, in addition to antenna current and distance from the antenna, the electric fields in earth (both E_{e1} and E_{e2}) are also dependent on soil (or water) conductivity. For study sites near the ELF antennas and grounds, Equations 2 and 3 describe the earth electric fields. Electric field intensities in the soil can be enhanced or diminished when in proximity to objects of differing conductivity such as rocks and roots. In addition, conductivity values for a given soil are not fixed but can vary according to moisture and temperature conditions. Because of these phenomena, measurements of electric field intensities in soil at the same location are more variable across seasons and years than magnetic fields.

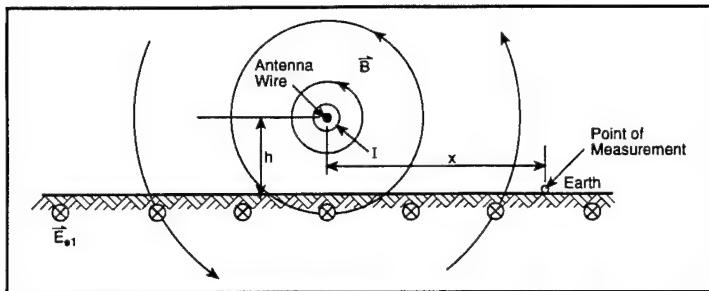


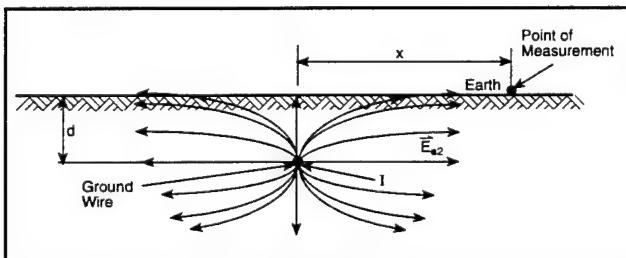
FIGURE 7. MAGNETIC AND EARTH ELECTRIC FIELDS GENERATED BY THE TRANSMITTING ANTENNA.

where: B = magnetic flux density
 E_{e1} = induced earth electric field
 I = antenna or ground wire current
 μ_0 = magnetic permeability in free space
 μ_r = relative magnetic permeability of medium

h = height of antenna wire
 x = horizontal distance to antenna wire
 σ_b = bulk earth conductivity
 j = $\sqrt{-1}$
 f = frequency of antenna current

$$|B| = \frac{\mu_0 \mu_r I}{2\pi \sqrt{x^2 + h^2}} \quad (1)$$

$$E_{e1} \approx -j f I \mu_0 \mu_r \ln \left(\frac{1.85}{x \sqrt{2\pi f \mu_0 \mu_r \sigma_b}} \right) - \frac{\pi f I \mu_0 \mu_r}{4} \quad (2)$$



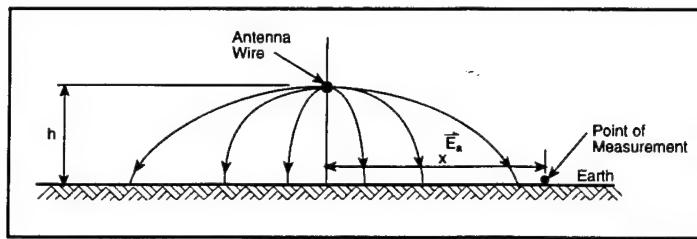
$$|E_{e2}| = \left(\frac{l}{\pi I \sigma_s} \right) \left(\frac{x}{x^2 + d^2} \right) \quad (3)$$

FIGURE 8. EARTH ELECTRIC FIELD FROM BURIED GROUNDING WIRE.

where: E_{e2} = conducted earth electric field
 l = length of ground wire

d = depth of buried ground wire
 σ_s = surface earth conductivity

Air electric fields (E_a) are the most variable of the fields generated by ELF antennas. The air electric field intensity is easily distorted in the presence of nearly all objects. Within ROWs or open areas adjacent to the overhead antenna, field intensities were predictable and measured values were reasonably repeatable (Equation 4). However, beneath the forest canopy the vertical (largest) component of the air field was almost completely shielded. Under these conditions, measured values were relatively small.



$$|E_a| = \left(\frac{2V}{\ln \left(\frac{2h}{a} \right)} \right) \left(\frac{h}{h^2 + x^2} \right) \quad (4)$$

FIGURE 9. AIR ELECTRIC FIELD GENERATED BY TRANSMITTING ANTENNA.

where: E_a = air electric field
 V = voltage on antenna wire
 a = radius of antenna wire

3. ECOLOGICAL MONITORING PROGRAM

Detecting anthropogenic effects on natural communities is a central problem in applied ecology [11]. It is a difficult problem because one must decide whether parameter differences are due to human intervention or to naturally occurring spatial and temporal variations. In the case of perturbations from EM exposure, this basic problem is exacerbated by uncertainties in the nature of EM effect mechanisms, and from this, proper metrics for relating exposure aspects (e.g., intensity, duration, waveform) to biotic responses [9].

The approach adopted in these studies was a design, considered optimal for environmental impact studies [11, 12], that measured biological variables at about the same time at treatment (EM exposed) and control (unexposed) sites before and after impact. Since the life of the ELF Communications System may be on the order of more than 30 years, assessment for possible adverse effects from the fully operational ELF System was the impact of most concern. The underlying concept is that data collected at the treatment site would exhibit the effects of both EM (76 Hz fields) and non-EM (physicochemical and biotic) factors. Preoperational data from the treatment site and all data collected at the control would show the effects of non-EM factors only. However, as exposures were uncontrolled, investigators had to address intermittent and/or relatively low intensity EM exposures experienced at treatment sites prior to full operation of the transmitters.

Over 335 variables on the physiology, development, behavior, and ecology of abundant biota residing near the ELF System were examined at upland, wetland, and riverine study sites. In nearly all cases, non-EM factors (ambient physicochemical and biotic) at study sites were also ascertained. Generally, spatial and temporal comparisons of parameters were performed using analysis of variance and intervention statistical techniques.

3.1 Study Sites

Maximal EM exposure at treatment sites was attained by establishing these sites as near to the antenna as possible. In some situations, study organisms (e.g., swallows and bees) foraged, or were naturally found, in open areas adjacent to the ELF System (Figure 3). In these cases, study sites were located within, or adjacent to, the antenna ROW. In other circumstances (e.g., soil organisms, herbs, and existing trees), treatment sites had to be offset deeper into the surrounding forest in order to avoid confounding of possible EM effects by the edge habitat created when the ELF System ROW was cleared.

Control sites were distant enough from the ELF System to be considerably less exposed than treatment sites, yet close enough to treatment sites to have similar physicochemical and biotic factors. At the time of site selection, other environmental studies monitoring for possible EM effects from transmission of electric power utilized one to three orders of magnitude difference between treatment and control exposures (Table 4). Accordingly, an order of magnitude difference for each field was employed as a minimal EM relationship for selecting study site pairs.

**TABLE 4. TREATMENT AND CONTROL EM RELATIONSHIPS
FOR ELF ENVIRONMENTAL STUDIES**

Study Variables	EM Exposure		T/C (order of magnitude)	Publication Year [reference]
	Treatment (T)	Control (C)		
Plant growth, bee behavior and mortality, small mammal and bird abundance	11 kV/m	0.2-0.3 kV/m	2	1980 [13]
Bee mortality, behavior, nesting activity	7-12 kV/m	0.2-0.4 kV/m	1-2	1981 [14]
Plant growth	12 kV/m	0.1-0.5 kV/m	2	1982 [15]
Plant growth	8.5 kV/m	0.3-0.4 kV/m	1	1983 [16]
Growth and endocrine response of lambs	4-7 kV/m 15-50 mG	0.01 kV/m 0.1-0.4 mG	2-3 2	1991 [17]
ELF ecological studies (during FOC)	0.01-40 V/m 0.2-45 mG	<0.001 V/m 0.001-0.2 mG	1-4 1-3	1994, 1990, 1988 [10, 18, 19]

In addition to maximizing treatment and control differences at 76 Hz, selections had to minimize the relative exposure to other EM sources, primarily those associated with electric power distribution, i.e., 60 Hz. In recognition of the fact that specifying exact EM values at either transmitting facility could be counterproductive in meeting biological requirements for selecting sites, the following EM exposure guidelines were established.

$$T_{(76 \text{ Hz})}/C_{(76 \text{ Hz})} > 10 \quad (5)$$

$$T_{(76 \text{ Hz})}/T_{(60 \text{ Hz})} > 10 \quad (6)$$

$$T_{(76 \text{ Hz})}/C_{(60 \text{ Hz})} > 10 \quad (7)$$

$$0.1 < T_{(60 \text{ Hz})}/C_{(60 \text{ Hz})} < 10 \quad (8)$$

where: $T_{(76 \text{ Hz})}$ = treatment site exposure due to operation of the ELF System

$T_{(60 \text{ Hz})}$ = treatment site exposure due to electric power use

$C_{(76 \text{ Hz})}$ = control site exposure due to operation of the ELF System

$C_{(60 \text{ Hz})}$ = control site exposure due to electric power use

By means of these exposure guidelines, IITRI sought to ensure that the intensities of the 76 Hz fields at selected sites were significantly greater at the treatments than those at the controls (Equation 5); that exposures at the treatment site were predominantly from the ELF System (Equation 6); that potential effects due to ELF exposure were not masked by similarly intense fields from electric power use near controls

(Equation 7); and finally, combining relationships in Equations 2 and 3, that differences in 60 Hz fields were kept to a minimum (Equation 8).

Selection of study sites began in earnest during 1983. In Wisconsin, where the antennas were already operating under near-operational intensities, EM exposures were easily measured and operational values accurately estimated. In Michigan, site selection was begun prior to exact positioning of the antenna ROW. Here, EM exposures estimated for candidate sites were based on assumptions of distance to antennas and bulk conductivity of the substrate. Except for minor adjustments, site selection in both states was essentially complete by the end of 1984 (Figures 10 and 11). (More exact positions of study sites for Michigan can be found in Reference 10 and for Wisconsin studies in References 18, and 19.)

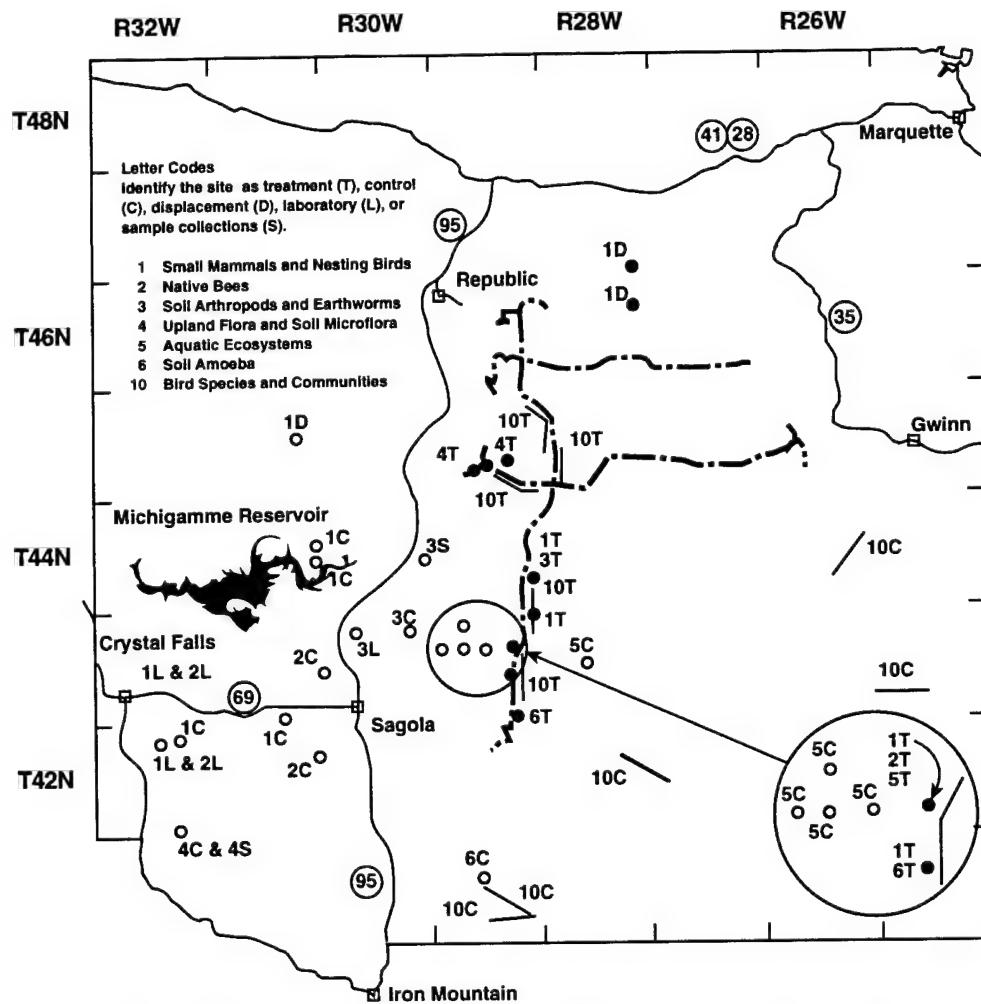


FIGURE 10. ELF ECOLOGICAL STUDY SITES IN MICHIGAN.

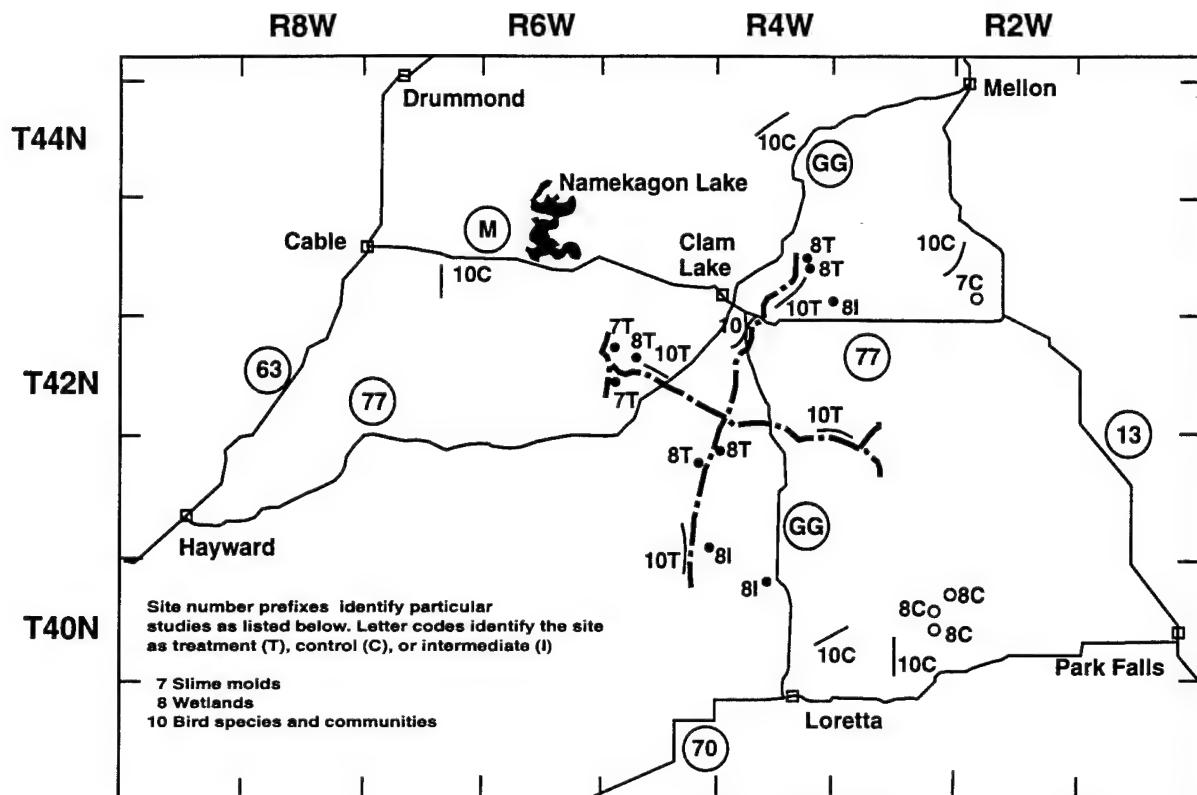


FIGURE 11. ELF ECOLOGICAL STUDY SITES IN WISCONSIN.

All studies monitored biological variables for organisms exposed to EM fields near the overhead antenna wire; four other studies also monitored biological variables near grounding terminals (Table 5). Wetland studies used intermediate sites in order to examine for potential effects along an EM intensity gradient. Study sites were not located close enough to transmitter compounds or well grounds to examine for effects from these ELF EM field environments. EM intensities in these latter two sections were low and more localized than at other system elements.

3.2 EM Exposures

At the onset of ELF monitoring studies, there was some uncertainty within the scientific community as to the most appropriate ELF EM exposure metric. In 1981, the research community concentrated on studying exposure to air electric fields, whereas now magnetic fields are receiving close scrutiny. The approach taken in these studies was that currently common in the scientific community, i.e., examining for effects from exposure to differential magnetic flux densities. Other issues of potential concern in ELF System monitoring include intensity windows, thresholds, temporal aspects (time-weighted average, cumulative exposure), intermittency, and synergistic interaction with the earth's geomagnetic field.

EM field intensities at 76 and 60 Hz were measured with probes developed and fabricated by IITRI [10]. All 76 and 60 Hz field data are reported as the root-mean-square values of the field magnitudes. The probes were used in combination with frequency-selective voltmeters and, where necessary, selective

**TABLE 5. RELATIONSHIP OF ECOLOGICAL STUDY SITES
TO THE ELF COMMUNICATIONS SYSTEM**

Study Organisms	State	Antenna Sites	Ground Sites	Intermediate Sites	Control Sites
Small mammals and nesting birds	MI	5	0	0	4
Native bees	MI	2	0	0	2
Arthropods and worms	MI	1	0	0	1
Upland flora and microflora	MI	1	1	0	1
Aquatic biota	MI	1	0	0	1
Soil amoeba	MI	1	1	0	1
Bird species and communities	MI	5	0	0	5
WI	5	0	0	0	5
Slime molds	WI	1	1	0	1
Wetland biota	WI	3	2	3	3
Total		25	5	3	24

Note: Table does not include release points, holding facilities, laboratories, or upstream controls used to track movements of fish.

frequency filters. These instruments provided the sensitivity needed to measure very low field intensities and the selectivity to discriminate between 76 and 60 Hz frequencies. The probes were calibrated prior to and following measurement surveys. All measurements and calibrations were conducted in accordance with IEEE Standard 644-1987 for the measurement of power frequency electric and magnetic fields. Voltmeters were calibrated annually against NIST traceable standards. The earth's geomagnetic field was measured with a flux-gate magnetometer that was calibrated annually by its manufacturer.

As part of IITRI's program of engineering support, annual measurement surveys were performed in order to characterize the ELF EM environment at study sites. Measurements included 76 Hz fields generated by the ELF System and 60 Hz fields resulting from electric power distribution. The earth's dc geomagnetic field present at each Michigan study site was measured during 1992 and 1993 surveys. Because the earth's geomagnetic field changes little over time and the amperage and voltage on the ELF antennas were constant over each surveyed period (Tables 2 and 3), yearly surveys were judged as adequate for most estimates of EM exposure. Although 60 Hz fields can be quite variable over time, all measures showed them to be markedly lower than 76 Hz intensities at treatment sites. Because of these relationships, 60 Hz fields were not considered as confounders in examining for potential biotic effects from 76 Hz exposure.

For the most part, EM exposures were uncontrolled by the research teams, and monitoring was performed both before and after transmitters became fully operational. This resulted in pre-FOC ecological data being collected under unexposed, as well as relatively intermittent and low intensity, conditions in

Michigan. In Wisconsin, near full intensity but intermittent exposures were the case prior to FOC. As a result, testing for effects in Wisconsin was limited to spatial comparisons (treatment versus control), whereas in Michigan, before-and-after comparisons were also examined by investigators. Most investigators treated 1989 as an operational year in Michigan comparisons. Although the Michigan transmitter was not considered fully functional until the fall, spring and summer EM exposures more closely resembled those from a fully operational system than those experienced under prior intermittent operation (Table 3).

Under FOC, the magnetic fields produced by the ELF System are quite low relative to those used to examine for acute bioeffects in the laboratory, but are roughly comparable to exposures experienced in high-voltage, electric power transmission studies (Table 4). Magnetic field exposures at ELF treatment sites ranged between 0.2-45 mG and were generally similar at comparable Wisconsin and Michigan sites (Figures 12 and 13). Magnetic fields are the least variable of the three fields produced by the ELF System, and they are responsible for generating electric fields in soil or water near the antenna. Investigators generally used magnetic fields as an indicator of overall ELF exposure when performing statistical regressions and correlation.

Although an item of concern to the NAS in its assessment of the Seafarer System [5], the potential for adverse effects from electric field exposure on edaphic biota has not been extensively examined by the bioelectromagnetics community. In Wisconsin, earth electric field intensities ranged between 50-1030 mV/m (Figure 14). In Michigan, the values at ELF grounding terminals ranged between 45-4000 mV/m, and antenna treatments were 10-350 mV/m (Figure 15). The literature indicates that short-term exposures to higher intensities than experienced at ELF study sites did not elicit acute changes in plants [20-23]. At 10-100 mV/m, aquatic exposures were similar to those at terrestrial antenna sites.

Air electric fields at ELF treatment sites ranged between 0.01 and 40 V/m. Maximal values were higher in Michigan than Wisconsin since several treatment sites were located directly beneath the Michigan antenna. Because of their high variability and low intensities relative to reported effects at other frequencies, air electric fields were not used directly in monitoring analyses.

Several of the possibilities arising from the unknown nature of EM exposure (i.e., threshold, duration, and field type considerations) were addressed in monitoring protocols. Maximal site differences in EM exposure optimized detection of potential thresholds. The duration of exposure was the same for both site pairs and, therefore, would not be a confounding factor in spatial comparisons. Similarly, by maintaining an order-of-magnitude differences between sites for all fields type, impacts from the ELF System could be detected without repetitious statistical analyses using each field type. In addition to field intensities, other data were collected that were, or could be, used to address temporal issues of EM exposure (time-weighted-averages, cumulative exposure, intermittency), as well as potential synergistic interactions between 76 Hz and dc geomagnetic fields.

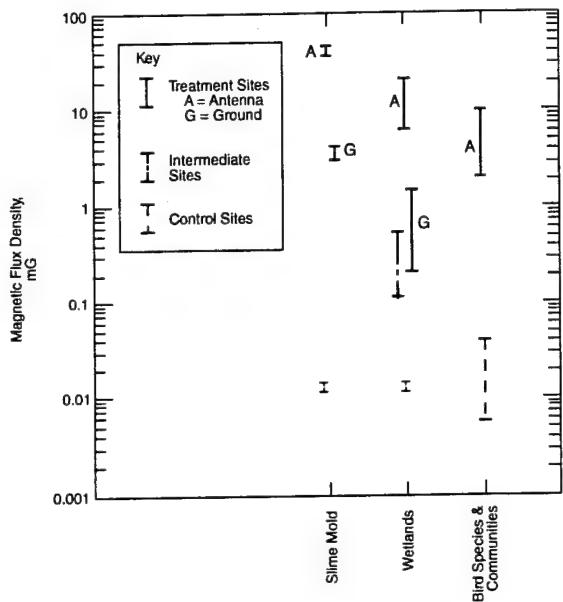


FIGURE 12. 76 Hz MAGNETIC FIELD EXPOSURE AT WISCONSIN STUDY SITES, 1985-1989.

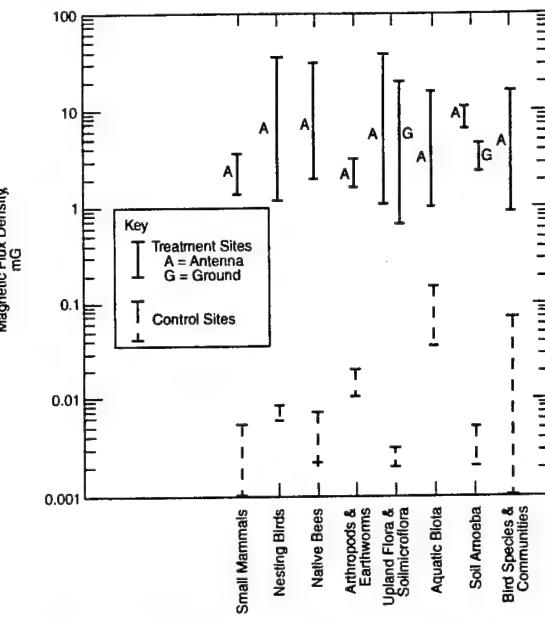


FIGURE 13. 76 Hz MAGNETIC FIELD EXPOSURE AT MICHIGAN STUDY SITES, 1989-1993.

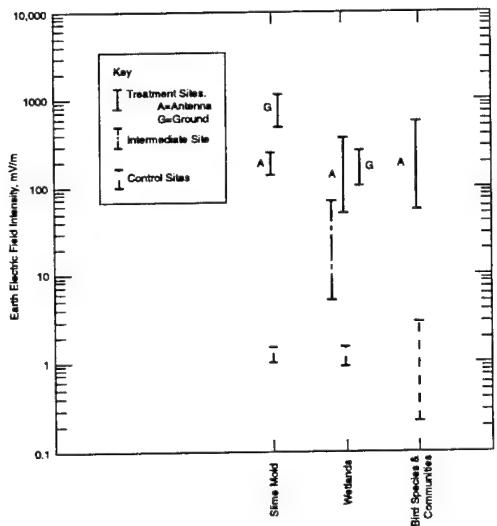


FIGURE 14. 76 Hz EARTH ELECTRIC FIELD EXPOSURE AT WISCONSIN STUDY SITES, 1985-1989.

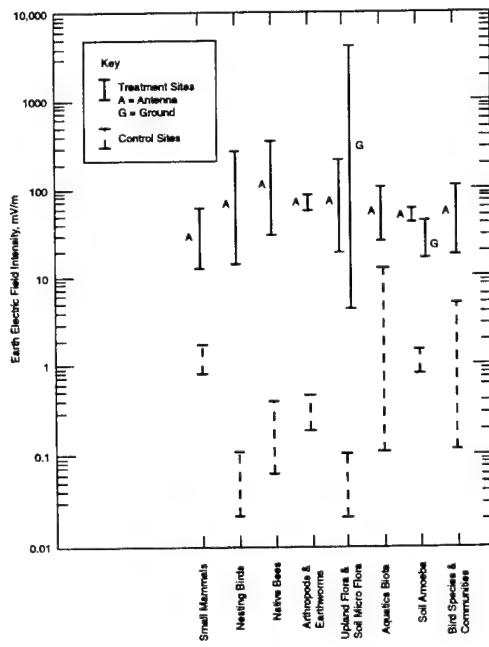


FIGURE 15. 76 Hz EARTH ELECTRIC FIELD EXPOSURE AT MICHIGAN STUDY SITES, 1989-1993.

3.3 Non-EM Environmental Factors

Ideally, treatment and control sites should be located in immediate proximity to each other. However, in order to assess for EM effects from the ELF System, study sites had to be separated by several miles to attain meaningful difference in EM exposure. Although sites were initially matched to insure as much similarity as possible, the replication of all important non-EM factors (physicochemical and biotic) was unlikely due to their inherent variability across years and these distances. As such, non-EM environmental factors (Appendix D) were measured and accounted for in many analyses.

Most investigators employed statistical protocols that divided EM exposure into two (preoperational and operational, i.e., before and after), or three (preoperational, intermediate, and operational) temporal regimes. In some cases, naturally occurring changes in non-EM factors coincided with EM exposure milestones in ELF System operation. For example, cumulative water temperatures during the preoperational period (1983-1985) were cooler than the study period average (Figure 16), while the intermediate exposure period (1986-1988) was warmer than average. With the exception of 1991, water temperatures during full operation of Michigan transmitter 1989-1993) were once again cooler than normal (Figure 17). Annual precipitation followed a somewhat similar pattern as cumulative temperatures (Figure 18).

Most parameters were examined using intervention analyses (BACI) or analyses of variance techniques. In the latter technique, data were often adjusted for non-EM factors using covariate analysis (ANCOVA). Meaningful relationships between non-EM site factors and EM exposure parameters were identified and examined using statistical correlations. Most, but not all, physicochemical variables were determined to be independent of EM intensities. This is important because statistical tests such as ANCOVA, which used non-EM factors to reduce variability, require these factors to be independent of the treatment, i.e., ELF EM exposure. In the only case where independence requirements were not met, investigators used ambient physicochemical factors in a growth model (see Tree Physiology and Growth, Section 4.1.4).

Investigators considered the interaction term as the most important aspect of the ANCOVA. As for significant BACI comparisons, a significant site-year interaction for ANCOVA indicated a change in site relationships over the exposure periods. These results were then interpreted graphically and/or by further statistical analyses such as regressions, in order to be sure that the changes were due to EM exposure.

Regressions indicated that response variables were more sensitive to non-EM factors than to EM exposure, if they were related to EM exposure at all. Even so, the most pertinent non-EM factors taken collectively could account for only less than half of the variability in a given biological parameter. Accordingly, conclusions of positive and negative associations between EM exposure and response variable need to be tempered by the ability of procedures to discriminate spatial and temporal differences. Several investigators provide statistical power or detection limits as a comparative measure of their ability to discriminate differences as statistically significant.

Statistical tests and covariates, along with corresponding results and conclusions, are reported in the following three major sections (4, 5, and 6) of this text.

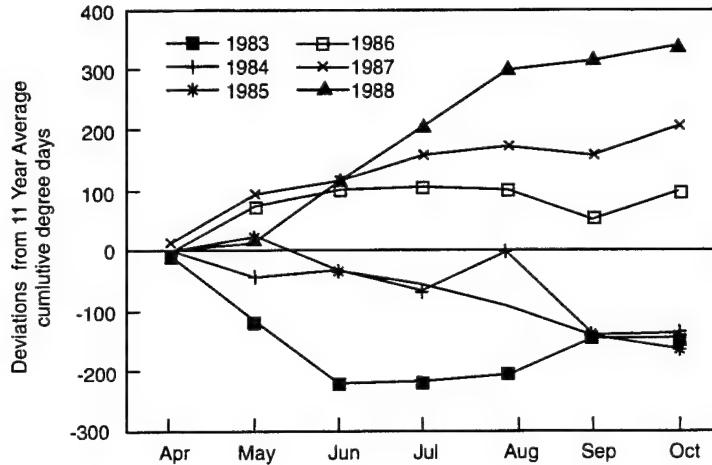


FIGURE 16. DEVIATION OF CUMULATIVE WATER TEMPERATURES IN THE FORD RIVER, MICHIGAN (1983-1988).

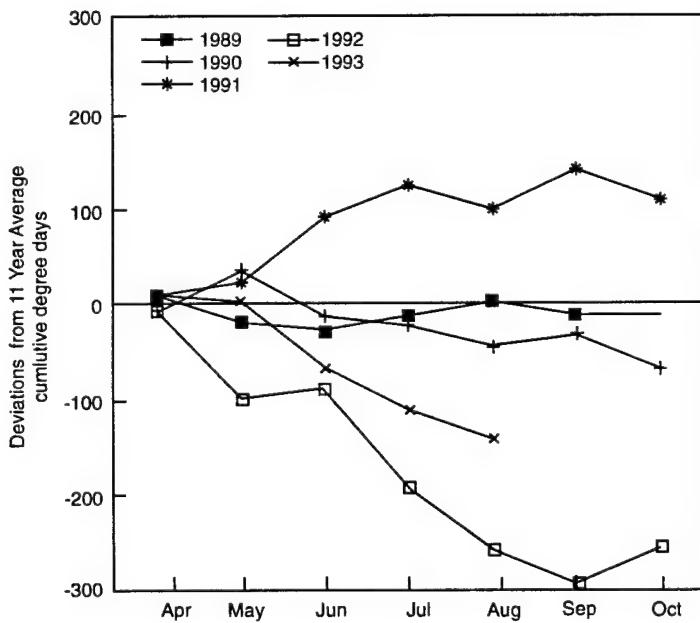
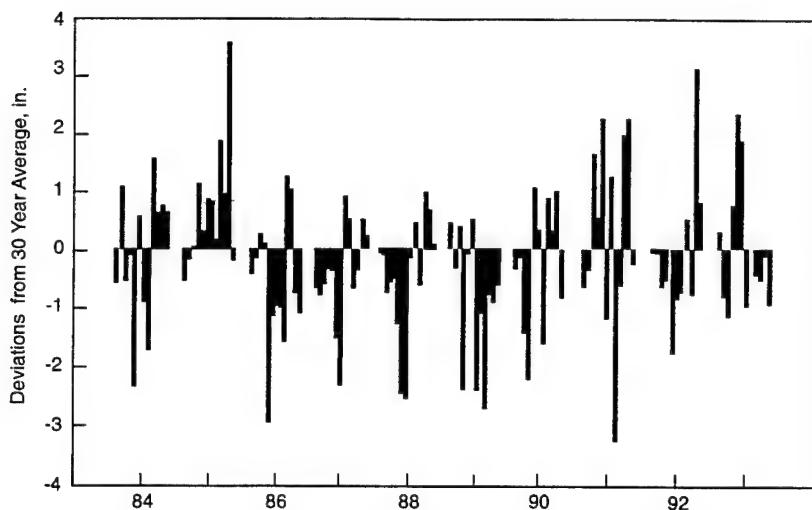


FIGURE 17. DEVIATION OF CUMULATIVE WATER TEMPERATURES IN THE FORD RIVER, MICHIGAN (1989-1993).



4. TERRESTRIAL STUDIES

4.1 Vegetation

Forest plants are the dominant biota in the ELF System area. They provide food and shelter to other organisms, and hold and modify soils. Any appreciable, adverse effect on plants could have an indirect but consequential effect on all other organisms in the area. Forests in the ELF System area are also important cultural and commercial resources to local residents and others.

Forest vegetation has been shown to be measurably affected by various anthropogenic factors, including EM fields. Exposure to EM fields at high intensities (kV/m, kG) resulted in acute effects on the germination and growth of various plants. At somewhat lower intensities (>20 V/m) and longer exposures, plant roots and fungal mycelia exhibited directional growth responses to the applied electrical field [24]. Studies associated with Project Seafarer at still lower intensities produced no credible indications of effects on plants [5]. All of these studies were performed using either relatively short exposure durations, or higher EM intensities, or different frequencies than generated by the ELF System.

Researchers from Michigan Technological University (MTU) monitored important trees, herbaceous plants, and fungi at actual ELF System intensities over longer periods than previously examined. Their broad objective was to monitor for possible chronic effects on forest productivity and health from exposure to low-intensity EM fields generated by the ELF System. They monitored the following for possible changes:

- herbaceous phenology and morphology
- pine and fungal symbiosis (mycorrhizae)
- pine root disease
- pine and hardwood physiology
- pine and hardwood growth
- litter production.

Productivity and health variables were monitored at three upland sites near the NRTF-Republic. Two treatment sites were situated so that one site was adjacent to an overhead antenna wire and the other was adjacent to a grounding element. A single control site was located more than 28 miles from any NRTF element. The antenna and control sites each consisted of hardwood tree plots (pole-size, maple-oak dominant), plots planted with red pine trees, and plots of herbaceous plants. The grounding treatment site consisted of plots planted with red pine only.

In conjunction with their studies of the soil's decomposition subsystem, researchers from Michigan State University (MSU) also monitored litter production. These studies used one treatment site located adjacent to the antenna ROW at the NRTF-Republic and one control site located about 5 miles west of the antenna. Both MSU sites were situated in a maple-dominated deciduous forest.

4.1.1 Herbaceous Phenology and Morphology

Herbs are sensitive to subtle changes in environmental conditions. Since herbs regenerate on an annual basis, they could have shown quicker responses to possible EM effects than longer-lived tree species. Phenological and morphologic characteristics were monitored as indicators of potential stress from exposure

to ELF EM fields. MTU investigators monitored 16 phenological and morphological variables of the starflower, *Trientalis borealis*.

The starflower is an abundant herbaceous species in many northern forested ecosystems including those in the ELF System area. Naturally growing starflowers were monitored on hardwood stands at antenna and control sites from 1985 through 1992. Phenological events examined were timing and rate of budbreak, leaf expansion, flowering, fruiting, and leaf senescence. Morphological characteristics observed were stem length, leaf length, leaf width, number of buds, number of leaves, number of flowers, and number of fruits. Investigators used analysis of covariance (ANCOVA), the Student-Newman-Keuls multiple comparison test, and regression analysis to examine their data.

Significantly lower numbers of plants with buds, flowers, and fruit occurred on the antenna site relative to the control in 1986, 1987, and 1988, however, significant site differences in the number of plants with flowers and fruits were not observed after 1988. The number of starflowers with buds was also relatively lower on the antenna site in 1989 and 1990; again, there were no significant site differences after 1990. The reason for this pattern is not known, but it does not appear to correlate with the plants' ELF EM exposure.

Analysis of data on the timing of initial budbreak and leafout indicated significant site-by-year interactions. However, researchers attributed this result to the weather-dependent initiation date of their observations across years, not to ELF EM exposure. ANCOVA did not demonstrate significant site-by-year interactions for the initiation dates of flowering, fruiting, or senescing of leaves.

Although covariates explained significant amounts of variation, ANCOVA indicated significant site-by-year interactions for rates of expansion in stem length, leaf length, leaf width, but not leaf area. Mean annual values for stem length, leaf width, and leaf length declined at both sites from 1985 through 1992. The pattern of decline was the same at both sites, and thus did not appear to be related to energization of the NRTF-Republic.

MTU investigators concluded that ELF EM fields did not significantly affect the phenological processes or morphological characteristics of a representative herbaceous plant.

4.1.2 Mycorrhizal Associations

Mycorrhizal fungi form a symbiotic relationship with the roots of trees. The fungi utilize organic compounds synthesized by the tree for their growth and "forage" for minerals and water in the soil using mycelia. In turn, the fungi provide the tree with minerals and water more efficiently than the tree roots alone. This relationship is considered essential to the satisfactory growth of nearly all tree species. Because the growth of fungal mycelia is dependent on physiologically produced intracellular electrical currents, other sources of electrical current, such as the ELF Communications System, may affect the fungi.

MTU researchers sampled red pine growing on plantation sites (antenna, ground, and control) monthly (May-October) from 1985 through 1993. They characterized both the morphological types produced by the

various fungal associations and quantified the types as numbers per gram of root. Data were analyzed using ANCOVA with precipitation covariates.

Throughout the study, Type 3 and Type 5 remained the first and second most common mycorrhizae encountered at the study sites. The total number of mycorrhizae per gram of root declined from 1985 to 1988, after which numbers increased slightly each year. Significantly fewer mycorrhizae occurred in 1988-1990 relative to 1985-1987 and 1991-1993 periods. ANCOVA using total precipitation and number of events with precipitation greater than 0.1 cm indicated no significant differences between sites or site-by-year interactions.

Because no significant differences were observed between sites in the types or number of mycorrhizae after the antenna became operational, researchers conclude that the symbiotic relationship between pine roots and fungi was not adversely affected by a fully operational ELF transmitter.

4.1.3 Root Disease

The occurrence of red pine mortality due to a lethal root disease was first documented on MTU plantations in 1986. Since stress can predispose plants to successful infection by pathogens, MTU investigators began monitoring the progress of the disease to determine if ELF EM exposure acted as a stressor.

The responsible pathogen was obtained from dead seedlings and mushrooms collected at the plantations. Isolates were cultured and clones identified. All clones responsible for pine mortality belonged to a single species, *Armillaria ostoyae*. Other fungal species were present at the study sites, but they were not pathogenic toward red pine.

Investigators surveyed the plantations on an annual basis, and scored pine mortality due to *Armillaria* by its pathology. The uneven distribution of root disease among the three plantations precluded direct comparison of sites. Accordingly, estimates of disease progress were made by deriving rate constants. ANCOVA found no significant differences in the rate of disease spread among antenna, ground, and control plantations. However, the variability in rate values within each plantation coupled with a modest number of *Armillaria* genets resulted in a relatively poor ability to detect sites differences. Researchers estimated that they were able to detect rate differences greater than 48 percent as significant about 50 percent of the time.

Overall, investigators conclude similar virulence among *Armillaria* genets at all three plantations, and no detectable ELF EM effect on root disease progress.

4.1.4 Tree Physiology and Growth

The uptake of water and nutrients are physiological factors important to optimum tree growth and development. The internal moisture status reflects the integrated effects of environmental conditions and overall physiology on growth. Nutrients act as osmotic regulators and as constituents of tissue and biochemical catalysts. When plants are stressed, changes in these physiological factors can predate perceptible changes in tree morphology or development.

Leaf water potential was measured as an indicator of the internal moisture status of red pine. These data were collected biweekly on all three plantations over the period 1986-1992. The data were analyzed using ANCOVA with precipitation, temperature, and humidity as covariates.

ANCOVA revealed significant site-by-year interactions for pine leaf water potential. Multiple range tests identified significant differences between the control and ELF EM-exposed sites in 1986, 1988, 1990, and 1992. However, the relationship of ELF EM exposed pine to controls was not consistent. In 1990 leaf water potential of pine at the ground site was greater than the control site, whereas in 1992 pine water potential was greater at the control than at the ground site. Based on the lack of consistency, MTU investigators concluded that leaf water potential was unrelated to ELF EM exposure.

In addition to leaf water potential, samples of pine needles and oak leaves were examined for their nutrient and cation content. The pines were monitored by sampling one-year-old fascicles from 15 seedlings in October of each year (1986-1993); northern red oaks were examined by collecting monthly samples of crown foliage during the summer (1985-1992). Needles and foliage were oven dried and analyzed for nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg).

ANCOVA (using a variety of covariates) indicated site-by-year interactions for N and K content of red pine in 1986 only. This appeared to be an artifact related to establishment of the pine seedlings. Analysis of pine data collected during full operation of the Michigan transmitter (1990-1993) showed significant correlations between magnetic flux densities and Ca (ground site), as well as K and Mg (antenna site). Because the correlations were not consistent between the sites, investigators reason that these results were caused by non-ELF site characteristics. ANCOVA of oak foliage data did not indicate any significant site-by-year interactions in nutrient concentrations of the foliage. Further analyses of the oak data failed to show significant site, month, year, or diameter (source tree) interactions. Investigators estimate that differences as small as 9-33 percent would have been detected 50 percent of the time for oak nutrients.

Overall, MTU researchers conclude no ELF EM effects due to either the uptake or the movement of water and nutrients.

Other studies have shown that plant productivity can be affected by natural and anthropogenic conditions, possibly including EM exposure. Growth parameters such as tree diameter and height are strongly correlated with total tree biomass. Accordingly, MTU researchers monitored the annual growth of economically important and abundant trees occurring in the ELF System area for possible effects to their productivity.

Investigators measured trunk diameter growth of a natural community of second-growth hardwoods (maple, oak, birch, and aspen) near the overhead antenna and at a control site. Red pine seedlings were also monitored at each plantation site. The basal diameter and total height of each marked seedling was periodically measured throughout the growing season from 1984 through 1993. Parameters related to tree productivity such as stand structure, ingrowth, and mortality were recorded for assistance in interpreting growth measurements.

Data were examined by using ANCOVA and a growth model. ANCOVA (using air temperature, soil nutrients, and soil moisture as covariates) found no significant differences between sites (all species) or site-by-year interactions for oak, birch, and maple. There was a significant site-by-year interaction for aspen growth. Multiple comparison procedures showed no pattern of significant differences clearly relatable to ELF EM system operation.

Because of a correlation between magnetic field exposure and a soil nutrient covariate, investigators developed a diameter growth model for each of the hardwood species as a more appropriate analysis. The model allowed testing of EM exposure on both the magnitude and pattern of total annual growth. The model accounted for the effects of intertree competition; physical, chemical, and climatic conditions; and the innate potential for growth at each site.

Annual growth patterns for all four species and growth residuals for oak and birch did not indicate any effects from ELF EM exposure. Annual growth residuals for red maple and aspen showed a pattern consistent with growth stimulation at magnetic flux densities between 1 and 7 mG (Figure 19). For aspen, the estimated maximum magnetic response was 0.14 cm (0.28 cm average growth per year, 1986-1993) and for red maple, 0.08 cm (0.13 cm annual growth per year, 1986-1993). Growth at the control site was used in estimating annual averages for comparative purposes. In the case of maple, note that several trees were lost at the treatment site resulting in negative annual growth estimates at the stand for 1990 and 1991.

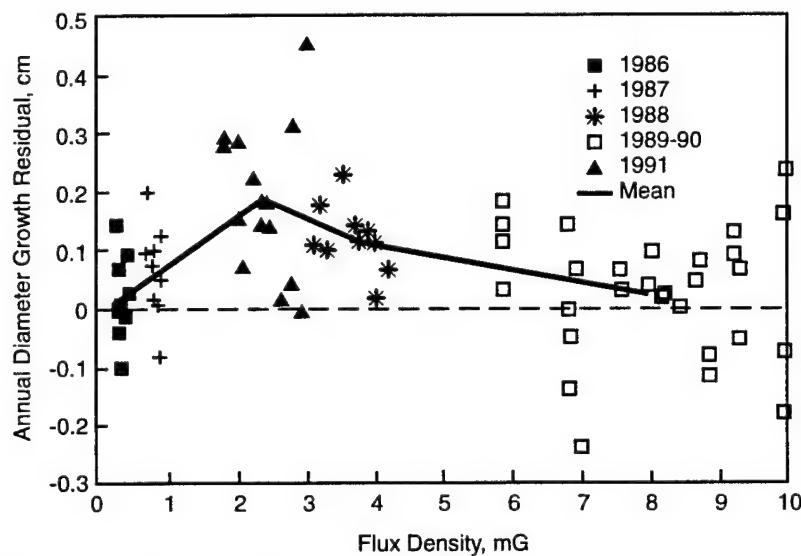


FIGURE 19. ESTIMATED EFFECT OF ELF MAGNETIC FIELD EXPOSURE ON THE DIAMETER GROWTH OF ASPEN TREES.

Annual diameter growth of red pine was generally greater at the antenna plantation than at the other two sites. ANCOVA using the current season's air temperature, total soil nitrogen, and available soil water indicated significant site differences, year differences, and site-by-year interactions. Multiple comparison tests showed that most changes in the relative rankings among sites occurred prior to full operation of the antenna.

In a related analysis, MTU researchers [25] found that ELF site differences in pine biomass were related to variations in site characteristics. As such, the significant differences indicated by ANCOVA may have resulted from unaccounted-for environmental factors and not ELF EM exposure. MTU investigators concluded no EM effects on annual diameter growth of red pine.

Annual height growth of red pine was generally greater at the control site. ANCOVA using the previous season's air temperature, soil nitrogen, soil water holding capacity indicated significant differences between years and site-by-year interactions but no significant differences between sites. Multiple range tests showed no significant differences between the antenna and ground sites; however, the control was significantly different from the other sites prior to, and during, full operation of the NRTF-Republic.

In order to further examine annual height growth, MTU used a modeling approach similar to that used to investigate hardwood diameter growth. Model results supported the possibility of stimulated shoot growth. A peak growth-response (window) may have occurred at 2.2 mG at the antenna site and 4.0 mG at the ground site. Seasonal shoot growth associated with peak exposures was 0.8 cm at the antenna site (38.5 cm average growth per year, 1986-1992) and 0.6 cm at the ground site (34.8 cm average growth per year, 1986-1992).

In deriving their results from the growth models, MTU investigators used magnetic flux densities as measured during intermittent and full operation of the NRTF-Republic; however, their approach did not address marked differences in the duration of the exposures. From 1986 through 1988, trees were exposed to ELF EM fields for only 1 to 7 percent of the growing season. Then, in 1991 when the antenna was under repair, average seasonal exposures (and durations) to hardwood trees on the antenna site were 8 mG (59 percent), 2.4 mG (28 percent), and no exposure (13 percent). IITRI evaluated aspen diameter growth as an example. Aspen did not show a peaking or "window effect" when annual average diameter growth of the stand was graphed against time-weighted-average magnetic exposures.

It should be noted that the detected effects may be caused by considerations other than ELF magnetic fields, such as the inadequacy of the model to satisfactorily account for the effects of covariates. Other indicators of productivity did not demonstrate a relationship to ELF EM exposure (see Section 4.1.5, Litter Production).

ELF EM exposure had no apparent effect on the pattern of seasonal growth but may have affected the amount of growth. Model residuals support the possibility of ELF EM exposure stimulating pine height growth and diameter growth of aspen and maple at about the same magnetic flux density levels. Several questions remain concerning the appropriate exposure metric and model adequacy. Additional analyses appear warranted prior to accepting that EM fields produced by the ELF Communications System stimulate tree growth.

4.1.5 Litter Production

The amount and quality of organic material produced by trees reflect the effect of ambient conditions on their physiology. In turn, the input of these materials (litter) is very important to the normal functioning of

the soil subsystem. For these reasons, researchers from MTU and MSU monitored the timing, total weight, and nutrient content of litter produced by dominant trees in the ELF System area for possible effects from exposure to ELF EM fields.

From 1985 through 1992, MTU researchers collected tree litter in traps (15/site) located on hardwood stands at antenna and control sites. The litter was dried, sorted, and weighed according to the following components: foliage, wood, and miscellaneous (e.g., seeds). Subsequent to weighing, the foliage component was subsampled for chemical determination of its nutrient content.

Split-plot ANCOVA (using cumulative air temperature as the covariate) indicated a significant site-by-year interaction for woodfall weight, but none for the miscellaneous or leaf components of the litterfall. Woodfall differences were attributed to the temporal and spatial disparity of storm intensities. The foliage component was emphasized in MTU analyses since it made up 75-80 percent of total litterfall and was the parameter most likely to reflect changes in tree physiology. Researchers estimated that site-by-year differences as small as 11-66 percent (foliage-wood) could be detected 50 percent of the time.

Average annual leaf litterfall was similar at both sites (322 g/m²/yr at the antenna site and 346 g/m²/yr at the control). The magnitude of litterfall at both sites was well within the range of values reported in the literature for other mixed northern forests. Nonsignificant weight and timing differences between sites were apparently related to species composition at the sites. The antenna site had higher numbers of red maple and bigtooth aspen than the control site, while the control site had higher numbers of northern red oak. Oak leaves remain on the trees longer than either maple or aspen.

ANCOVA (using climate and soil factors as covariates) showed relatively few significant site-by-year interactions for leaf litter nutrient content when examined either as a composite or as individual source species (oak, birch, aspen, and maple). Multiple range tests showed in all cases that significant differences existed between sites prior to full antenna operation. Inclusion of ELF EM fields as a covariate in ANCOVA did not alter or remove the site-by-year interactions, indicating that the differences were not related to EM exposure.

In addition to the MTU studies, MSU investigators examined leaf litter inputs at their antenna and control sites from 1984 through 1992. At the MSU sites, sugar maple and basswood were dominant. Soil types at both sites were matched and similar to those at the MTU sites. Average annual leaf litter inputs were 259 g/m²/yr at the treatment site and 278 g/m²/yr at the control site. Except for 1989, annual leaf litter inputs were always greater at the control site. ANOVA indicated no significant site-by-exposure interactions (1984-1988 versus 1989-1992) for maple, basswood, or total leaf inputs. Total inputs and between-year variation fell within ranges reported in the literature. The timing of leaf abscission was highly synchronous between sites.

Neither MTU nor MSU investigators conclude an ELF EM effect on the timing, total weight, or nutrient concentrations of tree litter.

4.2 Decomposition

In the ELF System area, nearly all of the annual forest productivity is shed as leaf litter. In turn, the rate of return of essential litter nutrients through the actions of the decomposition community on plant litter is a major regulator of forest production and thus, indirectly, an important determinant of ecosystem structure [26].

The community of organisms involved in plant litter decomposition is commonly categorized by size into macrobiota, mesobiota, and microbiota [27]. Macrobiota include such easily seen organisms as insects and earthworms. The mesobiota are much smaller and are dominated by arthropods such as mites and springtails. Both macrobiota and microbiota shred litter and redistribute the produced detritus throughout the soil. Microbiota (bacteria, fungi, and possibly protozoa) process the particulate detritus into soluble compounds and humus. The soluble compounds are immediately utilizable by plants; however, the complete disintegration of humus requires many years.

Changes in the population dynamics of decomposition biota have been shown to influence the rate of organic matter turnover. It has also been reported that weak EM fields affect insect orientation, earthworm behavior, and microorganism physiology. In nearly all cases, decomposers are closely coupled to ELF electric fields produced in the soil. Therefore, EM fields produced by the ELF System were examined as an anthropogenic factor, possibly affecting soil biota and/or the overall rate of litter decomposition.

4.2.1 Litter Breakdown

Researchers from MSU and MTU monitored the mass loss of leaf litter for possible ELF EM effects on the overall functioning of the decomposition community.

MTU investigators monitored the decomposition of red maple, red oak, and red pine foliage on their hardwood stands and plantations (see Section 4.1) from 1985 through 1993. Preweighted, bulk samples from a single source were placed at study sites in December of each year. Subsets of foliage samples were then retrieved from May through November of the following year. Retrieved samples were reweighed, and expressed as the percentage of original dry matter mass remaining. Investigators also examined the ash-free dry weight (AFDW) of oak foliage for comparative purposes.

Data were transformed to the arcsine square root to homogenize variances prior to ANCOVA. Two types of ANCOVA were used to statistically examine the data. An "Effects Model" examined for differences between sites and years as well as for site/year interactions, while a "Means Model" was used to identify trends among years. Covariates were based on seasonal inputs of energy and precipitation to the decomposition system. A covariate to address sampling date differences between years was also used.

ANCOVA (Effects Model) of data collected for samples emplaced in plantation plots showed no statistically significant differences in decomposition rate; however, at hardwood stands there were significant differences between sites, between years, and site/year interactions. Further examination using ANCOVA

(Means Model) suggested that the decomposition of litter on the antenna hardwood stands was accelerated over several years when the Michigan transmitter was near, and at, full operational status.

For all three foliage species, the annual decomposition rate pattern appears to have changed in 1988 from equal to higher rates on control to equal or higher rates on the antenna site (Figure 20). The site-by-year pattern of significant differences was most marked for oak decomposition rates, but was less obvious in maple or pine. Pine decomposition rates (least variable data) at the antenna hardwood stands did not vary as much across years as rates at the control stands (1986-1993). In this instance, it appears that decomposition rates

on the control site may have decreased over the 1988-1991 period. There were no significant site differences in 1992 or 1993 for maple, pine, or oak when the latter was examined as AFDW.

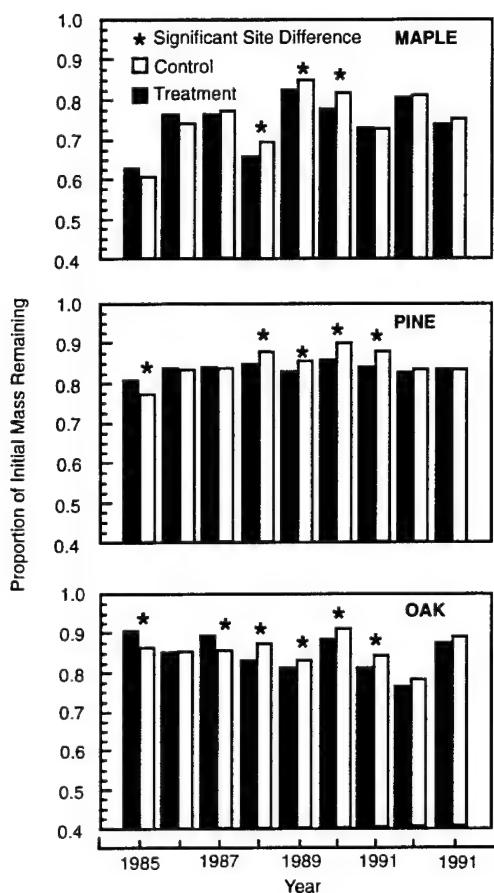


FIGURE 20. ANNUAL DECOMPOSITION OF MAPLE, PINE, AND OAK LEAF LITTER IN HARDWOOD STANDS.

Investigators from MSU also examined the decomposition of foliage along with macrobiota and mesobiota populations. They collected recently abscised, sugar maple leaves from around the periphery of each study site (see Section 4.1.5, Litter Production). During November, preweighed samples of dried leaves were placed in mesh netting on the soil surface within collection sites. Throughout the following year (May through November), subsamples were periodically retrieved, dried, reweighed, and then ashed (AFDW). Estimates of decay rates were then obtained from AFDW loss and the period spent at the study site.

Significant differences in leaf decomposition rates before (1984-1988) and after (1989-1993) the NRTF-Republic became fully operational were not detected by ANOVA. Sugar maple decomposition rates were significantly and highly correlated to the biomass of earthworm species present on the soil surface. Rate differences between years and groups of years (before and after full ELF System operation) were explainable by fluctuations in earthworm biomass (Figure 21).

MSU investigators conclude no EM effects on the breakdown of sugar maple, whereas MTU investigators found a temporary increase in the decomposition rates of red maple, as well as oak and pine, at stands exposed to ELF EM fields. Negative findings at MTU plantation sites and MSU maple stands may have been due to higher variability in decomposition rates at these sites. Positive findings need to be tempered by possible loss of fragments during retrieval, as well as by ostensible unilateral changes at the control site. If valid, MTU findings suggest a small, temporary (1988-1991) increase in the decomposition rates of litter exposed at hardwood stands. Treatment and control site differences were modest (5-8 percent) relative to year-to-year changes, which were as high as 14 percent.

4.2.2 Earthworm Biology and Ecology

Alternating electrical currents are known to affect earthworms often by forcing them to the surface of the soil. Even though ELF-induced currents in the soil are relatively weak, the behavior and other characteristics of the earthworm community were monitored for possible effects from chronic exposure to EM fields produced by the NRTF-Republic.

MSU investigators monitored earthworms along with other macrobiota, mesobiota (see following Sections 4.2.3 and 4.2.4), and rates of litter loss (previous section) for possible EM effects to the decomposition community. Soil and litter samples for earthworm studies were taken at two week intervals, May through October (1984 through 1993). Worms and their cocoons were extracted, identified, and enumerated.

Eight (of the nine species identified) were common to both treatment and control sites; however, the distribution of individuals and biomass among worm species was sharply different between sites. At the control site three species were equally abundant, while at the treatment site one species was dominant. The treatment site had fewer individuals, but markedly greater biomass than the control.

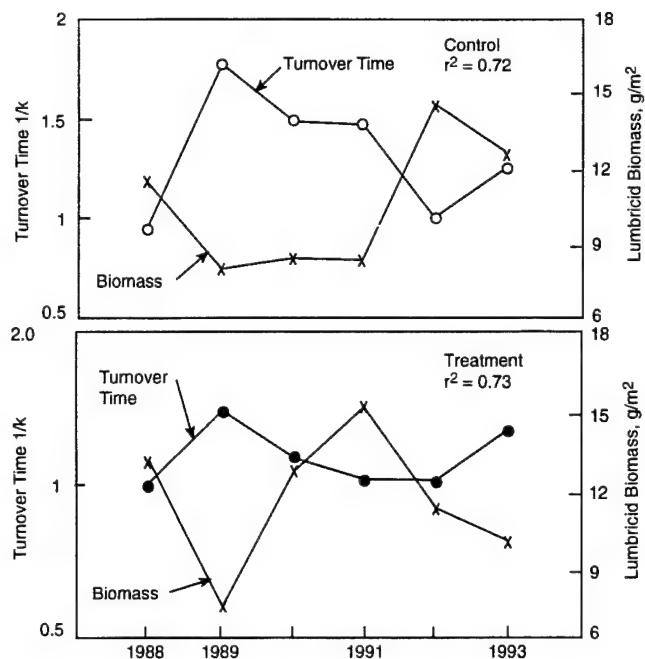


FIGURE 21. MAPLE LEAF DECOMPOSITION IN LITTER BAGS RELATIVE TO LITTER FEEDING EARTHWORMS.

BACI analyses indicated that significant changes in the intersite relationship of annual diversity occurred after the Michigan transmitter became fully operational. However, the sites were diverging, with most change occurring after 1988 at the control site (Figure 22). Temporal differences at the treatment site appear to be the result of reduced numbers of normally abundant species following a 1988 drought. BACI analyses showed no significant change in the intersite relationship of equitability indices.

MSU investigators also examined the population characteristics of *Apporectodea tuberculata*, the dominant worm species at the treatment site. Regression analysis of residuals indicated no significant differences between fully operational and the immediately preceding five-year period for vertical distribution, body mass of sexual adults (clitellates), or mass of cocoons. Similar results were obtained for another species, *Lumbricus rubellus*.

Regression analyses of residuals showed no significant changes in proportion of sexually active adults, density of reproductive individuals, or density of cocoons of *A. tuberculata* at the treatment site after the ELF transmitter became fully operational. Cocoon production rates were, however, significantly greater (23 to 33 percent) during full antenna operation. Of concern to MSU investigators was that environmental factors explained less variability during full operation of the Michigan transmitter than during the previous five years. In addition, the density of reproductive adults and cocoons was significantly lower in 1990 than preoperational average despite favorable moisture conditions.

In order to more closely examine reproductive parameters, researchers monitored cohorts of *A. tuberculata* placed into retrievable mesh bags. The mesh was small enough to contain the worms, yet allowed exposure to environmental conditions and ELF EM fields. ELF-EM exposed worms from the treatment site (Test 1991, Test 1993) and unexposed worms (Fire Tower) were partitioned between treatment and control sites. The worms were retrieved every two weeks and scored for proportion and body mass of reproductive adults, cocoon mass, and cocoon production.

Statistical results (ANOVA) of the mesh bag experiments were mixed (Table 6). The reproductive characteristics of previously unexposed worms (Fire Tower Provenance) showed significantly higher values at the treatment site. Worms previously exposed to ELF EM field for two years (Test 1991 Provenance) showed a higher proportion of reproductive adults when removed to the control site. However, differences in the body mass of clitellate adults, cocoon mass, and cocoon production (numbers basis) were not significantly different between sites. In the latter case, mass-based cocoon production showed a significantly higher

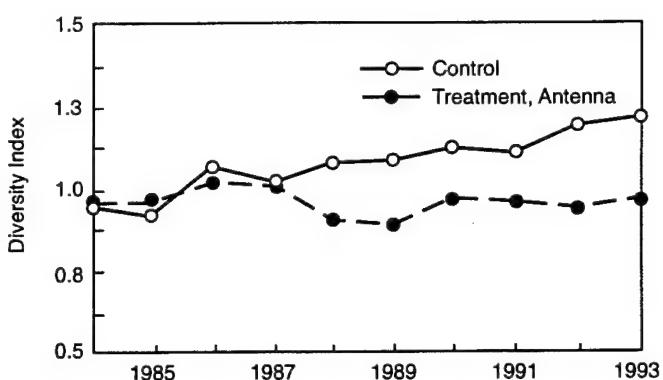


FIGURE 22. ANNUAL DIVERSITY OF THE EARTHWORM COMMUNITY AT ELF SITES IN MICHIGAN.

rate at the treatment site. Test 1993 Provenance worms (four-year exposure) showed no significant site differences when partitioned and incubated at the treatment and control sites.

TABLE 6. COMPARISON OF TREATMENT AND CONTROL RESULTS FOR APPORECTODEA TUBERCULATA GROWN IN MESH BAGS

Response Variable	Provenance		
	Test 1991	Test 1993	Fire Tower
Body mass of clitellates	No significant site differences	No significant site differences	Treatment significantly higher
Proportion of clitellates	Control significantly higher	No significant site differences	Treatment significantly higher
Cocoon mass	No significant site differences	No significant site differences	Treatment significantly higher
Cocoon production	No significant site differences	No significant site differences	Treatment significantly higher

Results indicate no effects on overall worm physiology, behavior, or the structure of the earthworm community. Statistical results on reproductive parameters are mixed. Comparisons of data collected during full operation of the Michigan transmitter and the preceding five years indicate no EM effects on reproductive characteristics. Mesh bag results suggest stimulation of the reproductive characteristics of a single species when previously unexposed individuals were initially exposed, and that removal from ELF EM fields had no effects.

MSU investigators interpret these data in yet another way. They believe that proper interpretation of non-bag data needs to account for population dynamics. Following this approach, investigators conclude that mesh bag and field population results are consistent with a subtle short-term depression of reproduction some period after initiating full operation of the Michigan transmitter. Nevertheless, there appears to be no lasting, adverse effects on earthworms from exposure to ELF EM fields.

4.2.3 Surface-Active Arthropod Behavior

In this project element, MSU investigators examined the major macrobiota and mesobiota (arthropods) inhabiting the surface layers of forested soils at sugar maple stands.

Diel and seasonal activity patterns of surface-active arthropods were assessed by consecutive, day and night, pit-trap samples taken once a week. Major groups trapped were springtails, mites, and ground beetles. Data were collected at treatment and control sites from 1985 through 1991. Community characteristics and seasonal activity of these major groups were analyzed using ANOVA and before and after, control and impact (BACI) analyses. The latter analyses compared data collected during full operation of the Michigan antenna and the preceding four years (1985-1988).

Although the sites differed in the relative proportion of abundant springtails, about 30 of the species captured were common to both sites. Species diversity at both sites was higher during full operation of the antenna than the preceding four years, while evenness indices changed little between these temporal periods. Seasonal activity patterns (as evidenced by the numbers trapped) were highly variable but correlated between the sites. BACI analyses indicated no significant change in the intersite relationship of community characteristics after the antenna became fully operational.

The few species of mites that were trapped did not well represent the overall community, and therefore were not examined from this aspect. However, three species were caught in numbers sufficient for examination of their activity patterns (i.e., numbers trapped). BACI analyses showed no significant change in the intersite relationship of mite numbers after the antenna became fully operational. Graphs of seasonal frequency of developmental stages of two species did not indicate any EM effects on their life cycle. The remaining species was not examined since catches consisted entirely of adults.

With the exception of a few rare types, the species composition of the carabid community was similar on both the treatment and control sites. Dominant species were the same on both sites. BACI analyses indicated a significant change in the overall diversity relationships of the communities after the antenna became fully operational. These findings were due to a significant reduction in diversity during the operational period. The reduction occurred at the control but not the treatment site, and therefore was not considered an ELF EM effect. No significant differences in evenness were revealed. Seasonal activity patterns of abundant beetle species during operational years were consistent with observations made during the preceding four years.

Although some analyses yielded significant results, investigators were unable to correlate numbers of captured biota to environmental conditions. As such, investigators concluded that numbers alone were unreliable indicators. Temporal changes in relative numbers captured showed synchronous activity at both sites, and there were no major changes to the arthropod community at the treatment site. From this MSU investigators conclude no obvious ELF EM effects on the surface arthropod community.

4.2.4 Soil and Litter Arthropod Ecology

In conjunction with other decomposers, MSU investigators concurrently monitored mesobiota inhabiting the litter and soils at sugar maple stands.

Community and population characteristics of major arthropods were determined from litter and soil samples taken during the growing season (May-October, 1985-1992). Biota were extracted by heat and sugar floatation techniques; springtails and mites were the most numerous taxa at both sites. Over the course of their study, researchers identified 73 species of springtails. In any given year, 44-55 of these species were recovered. BACI analyses showed a significant change in the intersite relationship of the equitability and diversity of springtails after the Michigan transmitter became fully operational. This phenomenon was due to significant increases in equitability and diversity at the control site.

Throughout the study, springtails were (on average) twofold more abundant on the control site than on the treatment site. Seasonal and year-to-year fluctuations in total numbers and developmental stages were highly correlated between sites. BACI analyses indicated that there were no significant changes in the intersite relationship of springtail density after the Michigan transmitter became fully operational. Fluctuations in overall number of springtails (2-3 times) was low relative to the range of temporal changes reported in the literature (3-29 times).

Although not affecting total numbers, significant between-year differences in springtail density occurred in several species. Two of three numerically dominant species common to both sites exhibited significant changes in treatment site density after the antenna was energized at full power. For one species numbers increased, for the other numbers decreased. From these mixed results and the lack of effect on community diversity, investigators deduce that the changes were due to non-EM ambient factors. They were unable, however, to correlate springtail densities to temperature, moisture, or other site factors.

Investigators were unable to identify all litter and soil mites; they therefore monitored three relatively abundant and easily recognized species. As for other arthropods, they found that the seasonal and year-to-year density of each species was synchronous between sites. Data for one of the three species was sufficient for statistical analysis; for it, BACI analyses showed no change in the intersite relationship of nymphal or adult density after the Michigan antenna was energized at full power.

MSU investigators conclude no effects on major mesobiotic decomposers from exposure to EM fields produced by the NRTF-Republic.

4.2.5 Streptomyce Ecology

Soil bacteria degrade organic molecules, nourish mycorrhizae, and influence neighboring microbial populations through their production of compounds such as antibiotics and vitamins. Streptomyce bacteria are part of the indigenous soil and root-related microbiota, and their populations do not normally undergo large fluctuations in habitats such as are present in the ELF System area. With regard to ELF EM fields, it has been reported [28-30] that low-intensity fields can affect the biology of similar microorganisms (e.g., slime mold physiology and bacterial orientation). For these reasons, the types and numbers of streptomycetes associated with local vegetation were selected for monitoring.

MTU investigators collected seven years (1985-1991) of streptomyce population data. Samples were taken monthly (May through October) from pine plantations at the antenna, ground, and control sites. Plate count data for streptomycetes associated with Type 3 mycorrhizal fine roots were expressed as morphotypes and numbers per gram of root. Bacterial-isolate samples were also analyzed for their ability to degrade complex organic molecules such as cellulose and lignocellulose.

Data for streptomyce morphotypes and numbers were logarithmically transformed prior to statistical analyses. Data were then examined by ANCOVA using weather-related covariates. Whenever significant differences were detected, pairwise comparisons of means were examined using other statistical options such

as least square means procedures. The overall power of the experimental design was calculated as detection limits, i.e., the percentage difference between two sample means that could be detected as significant ($p = 0.05$) 50 percent of the time.

Over the period of study, the number of morphotypes initially decreased and then stabilized at all three study sites. This pattern probably reflects the establishment of those types most capable of survival within the pine plantations. ANCOVA showed significant differences between years, but no significant site differences or site-by-year interactions. Significant shifts in morphotype numbers greater than 13-37 percent among years, or of 8-9 percent among sites, should have been detectable more than 50 percent of the occurrences.

Over the study period, total numbers gradually declined in a similar fashion at all sites. ANCOVA indicated significant differences between years, but none between sites. Investigators discerned no pattern in year-to-year results that could be attributed to ELF EM exposure. There were no significant site-by-year interactions, indicating a constant temporal relationship between sites. Significant shifts in streptomycete levels of 21-37 percent among years, or of 12-13 percent between sites, should have been detectable 50 percent of the time.

Representatives of each streptomycete type were also tested for their ability to degrade calcium oxalate, cellulose, and lignocellulose. Throughout the study, each morphotype degraded one or more of these organic compounds, indicating no change in their breakdown abilities.

MTU investigators conclude no overall ELF electromagnetic effects on these representative microbiotic decomposers.

4.2.6 Amoeba Biology and Ecology

Amoebae are common soil organisms that feed on bacteria. To the extent that protozoa affect the number and types of bacteria in the soil, they also become a potentially important factor in soil fertility. Laboratory studies on protozoa suggest that their orientation, growth, and/or physiology may be affected by EM exposure. As for other microbiota, amoebae are closely coupled to electric currents and fields produced by the ELF System. Indeed, actively growing (vegetative) amoebae exist in the soil as "naked cells," i.e., without the cellulose or chitinized coverings possessed by other microbiota.

In order to examine for possible EM effects from operation of the ELF System, MSU investigators monitored the following aspects of soil amoeba:

- species and strain characteristics
- growth
- population size and activity.

Data were collected at three sites (antenna, ground, and control) near the NRTF-Republic, Michigan. Soils were sandy loams with a sharp difference between an upper, organic horizon and a lower, mineral

horizon. Samples for taxon identification and population studies were taken with a coring device. Coring locations within study sites were determined using a numbered grid system and a random number generator.

Since the beginning of these studies, eight types of amoebae (variously identified to generic and species levels) have been consistently isolated using sample enrichment techniques. To date, no differences between years or between sites have been reported for the types of amoebae present.

In addition to taxon identification, the genetic diversity within a single species of soil amoeba, *Acanthamoeba polyphaga*, was monitored using isoenzyme analysis. This parameter was monitored from 1985 through 1988 when the scope of isoenzyme analyses was reduced. Limited study continued at all sites from 1989 through 1991 by monitoring the genetic heterogeneity of the same species reared *in situ* culture chambers. Soil populations of *A. polyphaga* were again monitored in 1991 and 1993 to determine if any changes in diversity had taken place after the Michigan transmitter became fully operational. BACI analytical procedures showed no significant changes in the intersite relationships (average Nei genetic distance) after the antenna reached FOC.

In order to determine the *in situ* growth (generation time), MSU investigators also monitored soil amoebae in culture chambers. The study protocol involved suspending *A. polyphaga* and a food bacterium *Escherichia coli* in a physiological saline within the chamber. ELF electric fields and currents were supplied to the chambers from buried collecting electrodes. During 1989-1991, periodic counts of amoebae were made to determine changes in the number of organisms. The genetic heterogeneity of the cultured amoebae was also determined at the onset and termination of the experimental period.

A logarithmic transform of the growth data provided a straight-line plot (numbers over time), which was then quantified by regression analysis. Using a modified t-test, the resulting slopes of the lines were compared to examine for statistically significant differences between sites. There were no significant differences in amoebal growth between sites, and investigators did not observe changes in the isoenzyme pattern of cultures incubated at study sites from their original cultures.

Soil samples were taken on a monthly basis (June through October) from 1982 through 1991. After enrichment, total numbers (vegetative plus cysts) and number of encysted forms were determined for each horizon using a soil-dilution counting procedure. In 1992, sampling was limited to the organic horizon during July, August, and September.

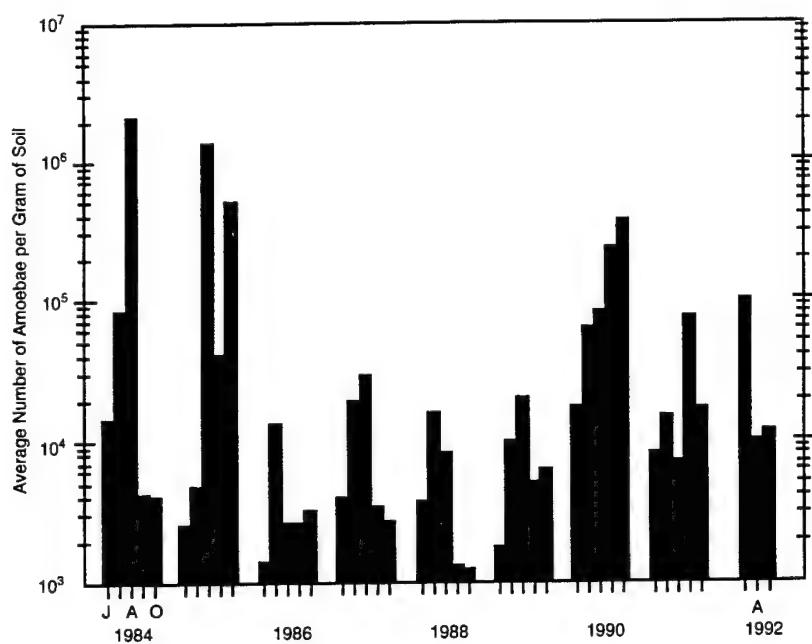


FIGURE 23. NUMBER OF AMOEBAE IN UPPER SOIL HORIZONS.

Total numbers increased from spring to summer and then decreased into the fall. Annual maxima most often occurred in July or August, although in 1991 and 1990 peaks occurred in September and October, respectively (Figure 23). The density of amoebae weakly correlated to soil moisture and by season pattern appeared related to temperature; however, the relationship of these factors to total counts could not be quantified. As such, ANCOVA was not used to analyze these data.

BACI analyses of annual maxima for total counts and cysts

showed that the ground/control site relationship of peak seasonal numbers in the mineral horizon changed significantly after the Michigan transmitter reached its FOC. Nevertheless, seven other BACI comparisons, including organic-horizon total numbers at the ground relative to control, showed no significant changes. Additional comparisons using ANOVA showed the density of amoebae was significantly different between sites for only four of the 46 months in which they were monitored. Significant sites differences in the number of encysted forms was about four times greater than density differences. The pattern of significant results was not consistent across seasons, years, or sites. The principal investigator concluded that there were no ELF EM effects on total numbers of amoebae or their encystment activity.

4.2.7 Slime Mold Physiology

Prior to these studies (1972-1978), investigators from the University of Wisconsin-Parkside (UWP) had reported that laboratory simulations of ELF EM exposures expected from (then) Project Sanguine depressed the rate of respiration and lengthened the mitotic cycle of the slime mold, *Physarum polycephalum*. Beginning in 1982, the same investigators initiated the restudy of these two physiological variables plus adenosine triphosphate (ATP) content for possible effects when molds were exposed *in situ* to ELF EM fields from an operating ELF transmitter.

Molds were exposed in separate studies to ambient EM fields present at the NRTF-Clam Lake, Wisconsin and to simulated fields in a University of Wisconsin-Parkside (UWP) laboratory. In both locations the molds were grown on agar substrates within culture chambers. The macroplasmodia in each chamber was subsampled weekly. One portion of each macroplasmodium was used to start a new culture for continued

EM exposure under the same regime as the parent; the other was taken to UWP for analyses. At UWP the macroplasmodium was transformed into microplasmodia, and then aliquots of the liquid culture were analyzed. Data were normalized to the protein content of each aliquot.

In situ studies at the Wisconsin transmitter were performed near an antenna site, a ground site, and at a control site seven miles from the nearest antenna element. At each site, culture chamber exposures were matched to either ambient electric fields or current densities present in the soil. Electric fields and currents were collected by buried electrodes and supplied to each chamber. In the laboratory, macroplasmodia were grown on the same medium, and in the same culture chambers, as the *in situ* studies. Laboratory cultures received either an electric field or current density similar to that present at the *in situ* ground site. Both cultures were exposed to the same magnetic flux density (also that present at the ground site).

Investigators abandoned examination of the mold's mitotic cycle after 1985 because of the ambiguous nature of their results. They determined that 1985, 1986, and particularly 1987 data on the metabolism (respiration rate and ATP content) were the most reliable. Using both ANOVA and linear regression statistical procedures, they initially analyzed 1987 data and then examined the entire three-year data set for possible ELF EM effects.

Laboratory data were used to evaluate the independent variables used in the experimental protocol, as well as to examine for possible EM effects without the confounding effects of environmental factors. Independent variable evaluated were replicates, time out of EM fields, intensity of EM exposure, and duration of EM exposure. There were no significant correlations between the variables, indicating that they were appropriate for ANOVA techniques.

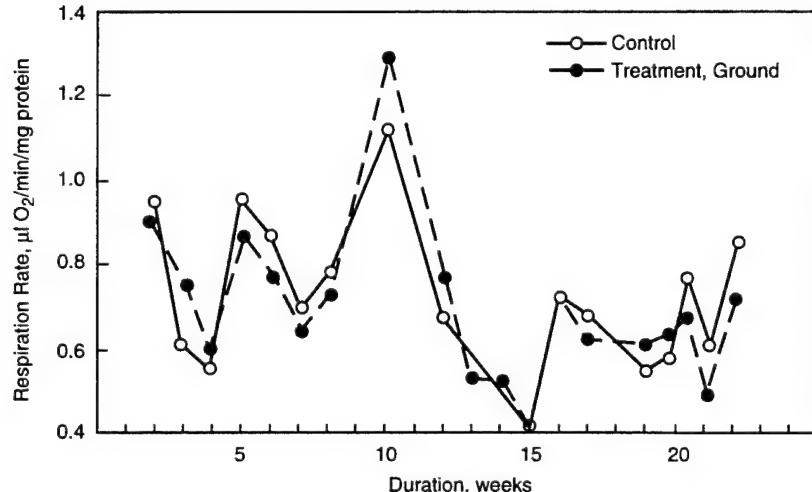


FIGURE 24. RESPIRATION RATES OF LABORATORY GROWN MACROPLASMODIA.

ANOVA of 1987 data collected for molds cultured in the laboratory indicated that the time out of the applied field (and associated growth chamber environment) significantly affected respiration rate but not the ATP content of the plasmodia. In the laboratory environment, the respiration rate declined with time. Both respiration rate and ATP content were significantly related to the duration of exposure (or age of culture). These latter changes were not systematic, and there was no apparent cu-

mulative effect due to the length of exposure (Figure 24). UWP investigators found no significant metabolic differences between exposed ($0.7 \mu\text{T}$ or $17.5 \mu\text{T}$, and 10 mV/m or 800 mV/m) and non-exposed plasmodia. ANOVA did not indicate any significant exposure/duration interaction effect on the respiratory parameters.

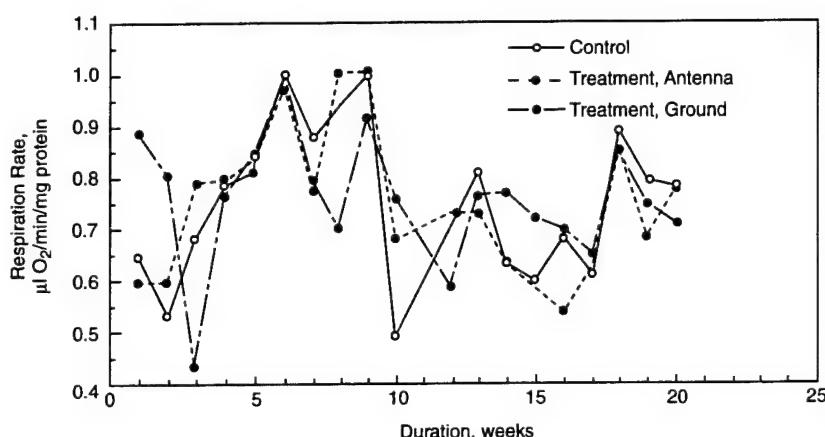


FIGURE 25. RESPIRATION RATES OF MACROPLASMODIA GROWN NEAR THE NRTF-CLAM LAKE.

intensities and duration. Respiration rates were less synchronized at the transmitter than that found in the laboratory (Figures 24 and 25).

Results for ATP content at the transmitter during 1987 differed from those obtained in laboratory cultures. ATP levels were not related to the duration of exposure but were significantly related to the type of exposure (i.e., electric field, current density). There were significant differences between sites (EM intensity regimes) and site-by-duration interactions.

Except for duration of exposure, there was no consistent pattern of results across years (1985-1987) suggesting some uncontrolled or unaccounted-for factor. Multivariate regression (for all data) found that no independent variable was a meaningful predictor of ATP content and only exposure duration showed a relationship to respiration rate. Correlation analysis supported these results. Significant correlations were between respiration rates and temperature, and respiration rates and duration of exposure. The relative importance of temperature and exposure duration could not be determined because they were highly collinear.

UWP researchers concluded that current studies failed to detect any reproducible, statistical significant differences in the mold's mitotic cycle, respiration rate, or ATP content. They acknowledge that their current conclusions are not consistent with the ELF EM effects that were reported by them in earlier published work.

In summary, the overall functioning of the soil's decomposition community was evaluated by monitoring rates of litter decomposition. Results were mixed: MSU investigators concluded no EM effects on the decomposition of sugar maple, whereas MTU investigators indicated a temporary increase in the decomposition rates of red maple, oak, and pine at hardwood stands, but not plantation sites, exposed to ELF EM fields. If valid, results could be consistent with a transitory effect smaller than naturally occurring fluctuations.

Statistical results for the respiration rate for plasmodia cultured at the Wisconsin transmitter during 1987 were similar to those obtained in laboratory simulations. The duration of exposure (or age of culture) was significantly related to respiration rate. There were no significant differences between cultures grown at antenna, ground, and control sites, nor were there significant interactions between EM

The decomposition of leaves was also monitored in Wisconsin wetlands. Here one of seven tests showed a significant difference between four exposure regimes. The significant difference suggested an enhanced rate of decomposition at antenna sites; however, further analyses showed that EM exposure was not an important factor in explaining the results.

Other investigations at upland decomposition study sites established no ELF EM effects on the structure of macrobiotic, mesobiotic, or microbiotic communities found on the soil surface, or in the litter and soil of treatment sites. Nor were effects found for such predators as beetles, spiders, amoebae, or slime molds. In all cases the variability of the communities' structural parameters were markedly larger than those of decomposition rates. No lasting or adverse effects on such less-variable characteristics as growth, health, behavior, and population biology resulted from magnetic field exposure and strong coupling to the soil's electric field.

4.3 Permeants

Permeants are highly mobile animals such as flying insects, birds, and mammals [27]. Species within these groups play ecologically important roles as pollinators, seed dispersers, and tertiary consumers. Many are of intrinsic interest as wildlife to local residents of, as well as visitors to, the ELF System area. The vertebrates may also serve as indicators of possible adverse effects to humans.

Species within these major classes of animals use geomagnetic fields, among other cues, for orientation and navigation. It has been reported that ELF EM fields can also influence the orientation of some avian and insect species. Yet other studies, conducted at relatively high EM field intensities, raise the possibility of chronic effects on vertebrate embryology, growth, health, and behavior from long-term exposure to low-intensity EM fields produced by ELF transmitters.

Characterizing ELF EM exposures to permeants is difficult for two reasons: (1) permeants are free to rapidly move across EM intensity gradients, and (2) their life histories are such that one stage may be spent in one subsystem and another stage in an entirely different subsystem. For example, young mice may be raised in burrows primarily exposed to electric fields in soil, while as adults, they may spend much of their time in trees or on the forest floor exposed to air electric fields. As a consequence, estimates of their EM exposure are less certain than more stationary biota.

4.3.1 Bee Behavior and Ecology

Over 40 species of native bees occur on the Upper Peninsula of Michigan. Having coevolved with resident plants, they serve as important, and perhaps unique, pollinators of flowering plants in the ELF Communications System area.

Increased dispersal, elevated levels of activity, lowered overwintering survival, and modified nest structure have been reported for honey bees exposed to the EM environment associated with electric transmission lines. Effects to bee orientation from fluctuations in the earth's magnetic field due to solar events and magnetic anomalies have also been reported. Accordingly, researchers from MSU monitored the foraging

activities, nest architecture, and mortality of native bees residing near the NRTF-Republic for possible EM effects from the operation of this transmitter.

Investigators focused data collection on two abundant species, *Megachile inermis* and *Megachile relativa*, as representatives of the native bee community in the ELF System area. Information on the behavior and mortality of both species was collected at two treatment sites located along the NS leg of the NRTF-Republic and two control sites over 10 miles from the antenna. Nesting activities were enumerated and timed by direct observation of foraging behaviors, while data on nest architecture and mortality were collected using trap nest techniques.

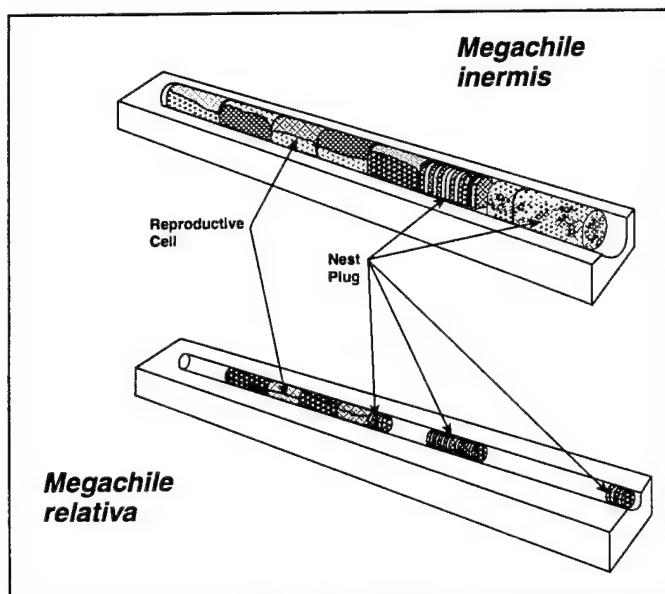


FIGURE 26. CUTAWAY VIEW OF TRAP NESTS COMPLETED BY *MEGACHILE INERMIS* AND *M. INERMIS*.

previous summer. Cells that showed no signs of emergence were opened to determine the development stage and condition of the bee.

The general linear model (GLM) procedure was used to analyze sources of variability in nest architecture (i.e., cell lengths, leaves per cell, nest plug lengths), adult weights, and the duration of foraging trips. Categorical data modeling (CATMOD) was used to compare intersite proportions (i.e., cells/nest, emergence, completions, gender, and mortality). Nest orientation preferences were tested by using log-likelihood ratio contingency analysis.

Foraging Activity. From 1983 through 1986, MSU investigators observed the activity patterns of various species of native bees. They found that the duration of trips for leaves needed to cap reproductive cells was short and less variable than other foraging behaviors. Because *M. inermis* was easily identified and active, its leaf foraging behavior was chosen as the best direct indicator of possible bee disorientation or

Nest trapping involved setting predrilled blocks of wood on shelved hutches and letting bees construct nests within the bore. Completed nests were overwintered at collection sites. During the spring, the nests were split open and data on nest architecture were recorded. Completed nests consist of a series of reproductive cells, nonreproductive spaces, and entrance plugs (Figure 26). Intact reproductive cells were removed from the nests, placed in individual plastic tubes, and then kept outdoors at ambient temperature until emergence of adults. Date of emergence, species, and sex of offspring were then recorded. Adults were released at the sites where their nest had been constructed the

agitation. Analyses using the GLM procedure showed no significant site-by-year (1983-1991) interaction indicating that a fully operational Michigan antenna had no obvious effects on foraging. Foraging durations would have had to differ by as much as 29 percent before they could have been detected as significant.

Nest Architecture. When honeybees were exposed to EM fields produced by high-voltage transmission lines, they altered their hive architecture by producing fewer cells and increasing the amount of propolis at the entrance. If EM fields disorientate them, the bees may also gather resources more slowly, indirectly resulting in altered nest architecture. In order to examine for these possibilities, researchers monitored the size, number, and linings of reproductive cells; the length of nest plugs, as well as, orientation preferences for nests constructed in the ELF System area.

Average length of reproductive cells at each site was determined as one indicator of nest architecture. The site-by-year interaction (1985-1991) was statistically significant for *M. relativa* but not significant for *M. inermis*. In the case of *M. relativa*, cell lengths decreased over the course of the study; however, lengths decreased by a greater amount at the controls than at the treatment sites. Overall, cell lengths at treatment and control sites became more similar sites after the antenna became fully operational. The size of the change for *M. relativa* (0.2 mm out of 11.1 mm, or 1.8 percent) was smaller than detected between genders, seasons, or years. As there were no marked changes at the treatment sites after the antenna became fully operational, investigators conclude some non-EM factor(s) common to both sites exerted greater influence at the control sites.

The number of reproductive cells per complete nest ranged from 1 to 12 for *M. relativa*. CATMOD found significant differences between sites and years, but no significant site-by-year interactions or significant changes at the treatment site after the Michigan transmitter became fully operational. These results indicate that none of the cell number differences were related to full operation of the antenna. The number of cells in a complete nest of *M. inermis* ranged from 1 to 8. In all years, the treatment sites had more cells per nest than nests at the control sites. There were no significant differences between before and full antenna operation indicating that site differences were not related to ELF EM exposure. Investigators estimate that at least a 1 cell per nest change (site average) could have been detected as significant.

GLM analyses did not demonstrate any ELF EM effects on the number of leaves per reproductive cells made by *M. relativa*. However, the number of leaves per reproductive cell of *M. inermis* increased in 1990 and 1991 compared with earlier years. The GLM model estimated that the control areas decreased by 0.1 leaf per cell after the antenna became fully operational, whereas treatment areas experienced an increase of about 0.6 leaf per cell after FOC. If real, investigators conclude that the increased time to add 0.6 leaf would not adversely affect reproductive output, nest parasitism, or bee predation.

GLM of nest plug length for *M. inermis* confirmed that the plugs were longer at control sites, and have been so since initiating study on this parameter in 1985. The analyses also showed that there was not any significant temporal change in plug length at the treatment sites. Consequently, ELF EM fields do not appear to have affected nest plugs for this representative species.

Bee preferences for orientating their nests were analyzed using a Log-Likelihood Ratio Contingency test. Only data for *M. relativa* was analyzed, as nest numbers for *M. inermis* at control sites were very small. Results indicate a consistent preference for nest orientations over the years but that the preferred direction was different between the sets deployed at a given site. Investigators conclude that orientation preferences were probably due to shading or proximity to resources.

Mortality. High voltage transmission lines have also been reported to lower the overwintering survival of honeybee colonies. MSU researchers compared the mortality of bees overwintered at treatment and control sites in order to examine for a possible similar effect from EM fields produced by the ELF System. They also scrutinized gender and weight as indicators of more subtle effects to the resident populations.

Prior to emergence of adults from reproductive cells, native bees are subject to mortality during any of several developmental stages, i.e., egg, larva, prepupa, pupa, or adult. Failure to emerge was used as an indication of morbidity. Prewinter mortality was related to the egg and larval stages, and overwinter mortality to the prepupal and later stages. Initial studies by the MSU investigators showed that prewinter mortality was primarily related to non-EM environmental conditions. For this reason and because the prepupal stage receives the longest duration of EM exposure, overwintering mortality was selected for monitoring.

One confounding factor in determining overwinter mortality for native bees was the inability of investigators to distinguish the prepupa of *M. relativa* and *M. inermis* from that of the parasitic bee, *Celioxys*. Since both host and parasite receive the same EM exposure, analyses were performed on their combined mortality data. Mortality was analyzed both as a percentage of reproductive cells and as a percentage of nests with at least one mortality. Data for nests constructed during full operation of the NRTF-Republic (1989-1993) and two prior years (1987-1988) were analyzed using CATMOD procedures.

Site-by-operational condition was not significant for *M. relativa* (plus parasite) overwinter mortality. However, the mortality within *M. inermis* nests and cells (plus parasite) was significantly greater at treatment sites after the Michigan antenna became fully operational. Before the transmitter became operational, overwintering mortality at the treatment sites was about 60 percent of that experienced at the control site. After the transmitter became operational, the mortality was about the same at both sites (Figure 27). The inference of intrinsic, mortality differences between sites prior to full operation of the antenna was based on only two years of data (1987 and 1988). There was no consistent pattern of higher mortality at treatment sites.

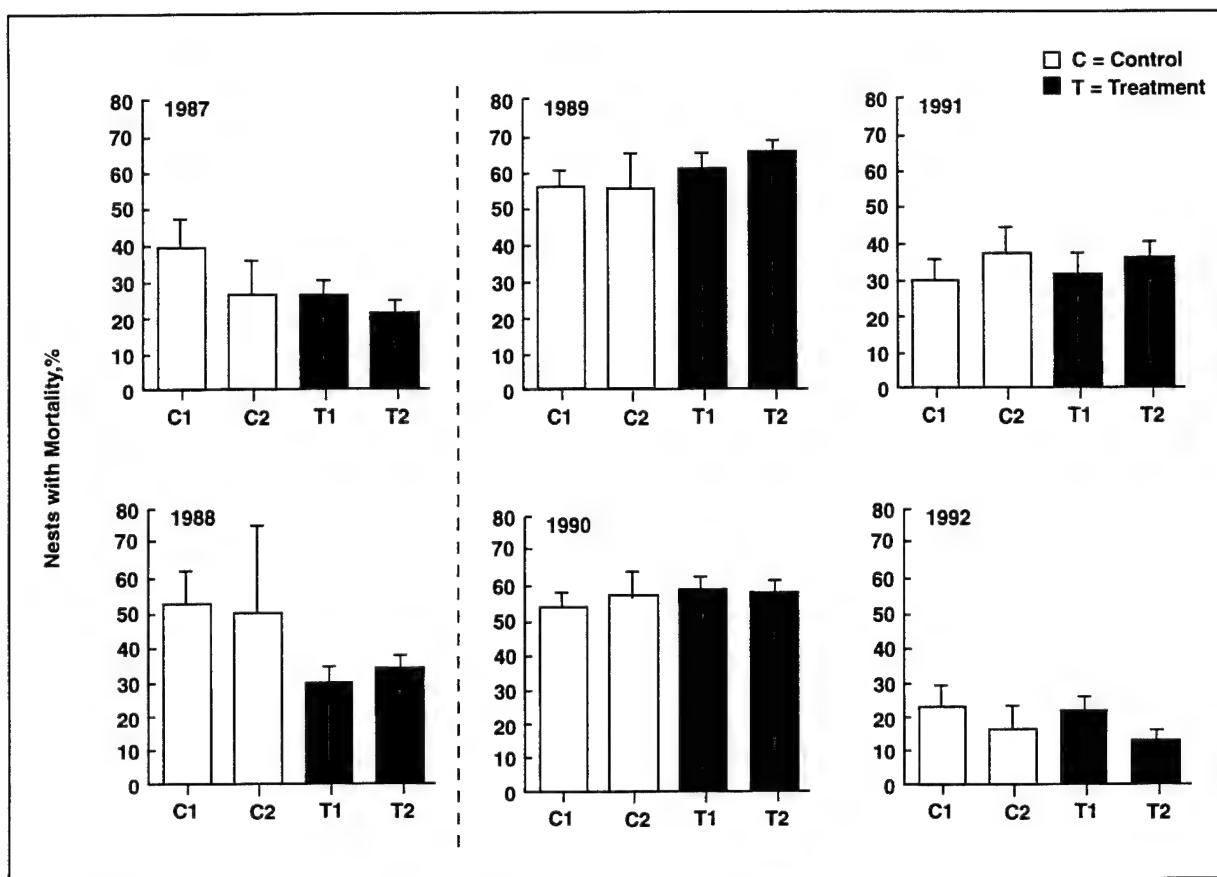


FIGURE 27. OVERWINTER MORTALITY OF *MEGACHILE INERMIS* PREPUPAE (1987-1992).

In order to further examine their preliminary results, MSU investigators transferred nests constructed at a treatment site during 1990 and 1991 to a control site for overwintering. CATMOD procedures indicated that the overwintering site, but not the construction site, was a significant source of mortality for *M. inermis* plus its parasite, *Celioxys* (Figure 28). Transfer results support the idea that winter conditions at the treatment site caused greater mortality than winter conditions at the control site.

In summary, statistical results indicate an association between ELF EM exposure and mortality and a few nesting biology parameters.

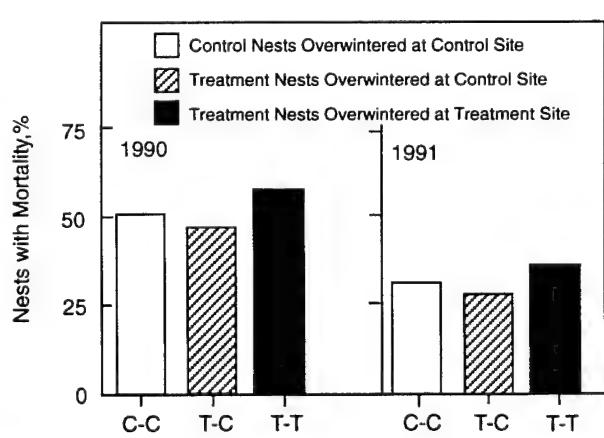


FIGURE 28. OVERWINTER MORTALITY OF *MEGACHILE INERMIS* PREPUPAE IN TRANSFERRED AND UNTRANSFERRED NESTS (1991-1992).

Significant differences were small and the results were sporadic, localized, and inconsistent between species. Overall, the results do not demonstrate any pattern of EM effects as to disorientation, parental investment in offspring, or stress response. The vigor of temporal comparisons was somewhat diminished by the relatively small sample sizes taken prior to full energization of the transmitter. Even if valid, the absolute size of significant differences was neither large nor consistent enough to raise concern to investigators about ELF EM exposures to pollinating insects.

4.3.2 Bird Behavior, Biology, and Ecology

In order to determine if operation of the ELF System affected resident avians, researchers monitored important biological and ecological characteristics of birds from 1982-1993. Organismal aspects, including developmental, reproductive, and behavioral characteristics were examined by MSU investigators using tree swallows as a representative species. The black-capped chickadee, a permanent resident on the Upper Peninsula, was used for MSU physiologic studies. Ecological characteristics of the bird communities in the Michigan and Wisconsin ELF System area were monitored by ornithologists from the University of Minnesota-Duluth (UMD).

The basic MSU design was an ANOVA with three treatment levels, preoperational, no EM exposure (1985, 1986); level 1, low level EM exposure (1987, 1988); and full operational EM exposure (1989-1993) on treatment and control sites. The project used five treatment sites in, or immediately adjacent to, the NRTF-Republic ROW and three control sites with habitats similar to the treatment sites. Control sites were located 12-18 miles west of the antenna and had cleared areas (sham ROWs) that were treated (plantings, brushing, etc.) the same as the antenna ROW.

Embryology. Prenatal developmental stages have been shown to be particularly sensitive to many types of environmental perturbations. Although different from the fields produced by the ELF System, some waveforms and intensities have been reported to have a direct effect on the embryonic development of birds. In addition, indirect effects on development would be feasible should EM exposure affect parenting behavior. Based on these premises, the prenatal development of tree swallows nesting near the ELF Communications System was also monitored for possible EM effects.

Eggs of tree swallows were collected at treatment and control sites after four days of incubation. Each egg was coded so that the investigator who examined for abnormalities was unaware of the source site. Embryos were dissected from the egg, preserved, and then examined microscopically. The following were assessed for each embryo: developmental stage, brain, eye, ear and branchial arches, heart, spinal cord and somites, limb buds, and extra-embryonic membranes, as well as flexion and rotation of the embryo.

Embryological data collected from 1986-1993 was analyzed using chi-square contingency tables. The frequency of abnormalities at both sites was greater after the Michigan transmitter became fully operational than before 1989. In two of the five years of full operation, the incidence of abnormalities was higher on the treatments sites; in the other three years the incidence was higher on the control sites. There were no statistically significant differences in the number of abnormalities on treatment and control sites for any single

year. Throughout the study, the incidence of abnormalities occurring in the ELF System area remained consistent with the proportion of swallow hatch failures reported in ornithological publications (i.e., 15-20 percent). Investigators conclude there were no ELF EM effects on swallow embryos.

Since avian embryos must develop in a closed system, the resources allocated to each offspring during oogenesis could have a marked influence in determining chick survival. To determine whether operation of the ELF System adversely affects the amount of nutrient deposited, each egg was weighed and measured at the time of collection. Weights of eggs were independent of operational status of the antenna but were significantly related to site and year. There was a significant site-by-operational period interaction. Mean egg weight data show a decreasing trend on both treatment and control sites from the preoperational to fully operational period. During full operation, egg mass means were higher on the treatment sites for two years and on control sites for three years. Only one year was the difference significant, in 1992 mean egg mass was higher at the treatment sites. Investigators conclude that the overall results did not support an ELF EM effect on egg mass. Similar results and conclusions were obtained for egg volumes.

Site differences of 1 percent and period differences of 5 percent could have been detected as significant 70 percent of the time. As such, investigators are confident that they could have detected small ELF EM effects on swallow egg mass, if one had occurred.

Fecundity, Growth, and Development. Once a clutch was completed, the mother spent most of her time incubating the eggs. After hatching, she was the main contributor in brooding of the young for several more days, after which both parents equally shared their time feeding the young.

Direct effect of EM exposure on reproductive physiology, postnatal growth, and behavior of vertebrates has been reported at ELF frequencies. EM disturbances of parental attentive behavior could have been indirectly influential as they are dependent on parents for food and warmth. The size of nestlings at the time of fledging was of particular interest to MSU because when the young become independent they must be substantially self-sufficient and therefore their maturity can affect their likelihood of survival. Accordingly, MSU investigators monitored the fecundity, postnatal growth, and mortality of tree swallows for possible direct (EM) or indirect (parental behavior) effects from operation of the NRTF-Republic.

Studies were carried out in clearings where arrays of nest boxes had been erected (Figure 3). Active nests were checked daily or every other day to determine the dates that eggs were laid, the number of eggs, hatching dates, and mortality. The growth and development of the nestlings were then monitored until all of the young fledged. In order to facilitate the organization of study elements, MSU researchers partitioned events into an incubation phase (which would include embryological events) and a postnatal, nestling phase. The former represents the time from egg laying to hatching, while the latter from hatching to fledging of the young.

All data (1985-1993) on clutch size and young hatched per nest were examined using nested analysis of variance (ANOVA). This statistical procedure found significant differences in clutch sizes neither between sites, years, nor operational periods. There was, however, a significant site-by-operational period interaction.

MSU investigators attributed the interaction to an increase in clutch size on control plots from preoperational to operational periods. Hatch rates (mean number hatching per nest) and likelihood to hatch were examined by NANOVA and chi-square tests, respectively. No significant differences in proportions of eggs hatching were detected between sites during any year or operational categories; there were no significant interactions of sites-by-categories. Significant year differences did not match the pattern of EM exposure.

Investigators were 70 percent confident that they could detect differences greater than 6 percent for clutch size and hatch rate as significant when they compared sites. When comparing operational status they were similarly confident of detecting differences greater than 9 percent for clutch size and 21 percent for hatch rate.

In order to examine nestling growth rates, periodically measured values were fit to models. Body weight, tarsus length, and ulna length data were fit to logistic models, whereas wing length data was fit to an exponential model. The models produced parameters (e.g., rate constants or rate at the inflection point) that were then examined along with other non-rate parameters (maximum value, age at maximum value) by NANOVA.

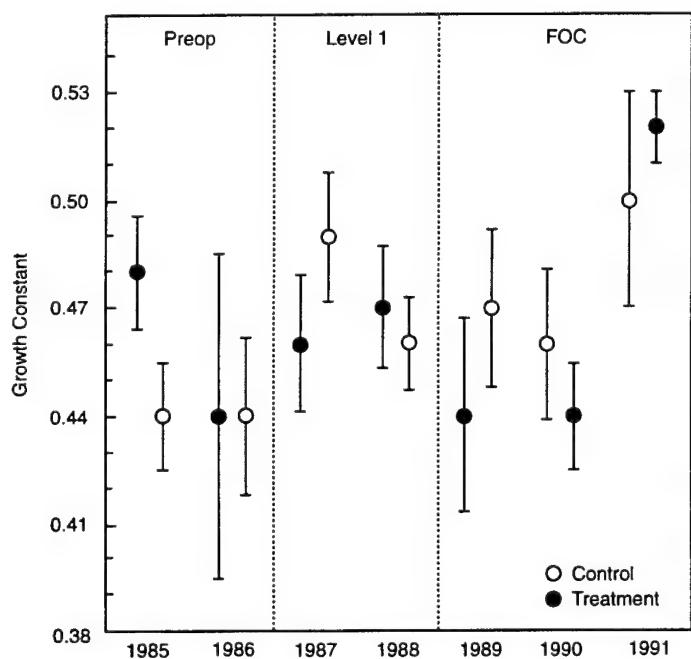


FIGURE 29. TREE SWALLOW MASS GROWTH CONSTANTS (1985-1991).

Body mass growth constants (Figure 29), inflection points, maximum mass, and age at maximum mass showed no significant differences between various operational conditions. Year-to-year (1985-1991) differences were highly significant for all of the growth variables. For all significant site-by-year interactions, mean values were significantly different during preoperational exposure. However, the means converged and were not significantly different during full operation of the transmitter. For all variables, except for age at maximum mass, the control means converged on treatment means, which had remained relatively constant. For maximal mass, the means on both sites converged during the operational period.

Analyses of means for growth constants, inflection points, maximum length, and age at maximum length for tarsal and ulnar bones, as well as wing growth, exhibited similar statistical results as body mass. ANOVA of data (1986-1991) on developmental landmarks (i.e., bird age at eye opening, Figure 30) and feather eruption were also similar to body mass.

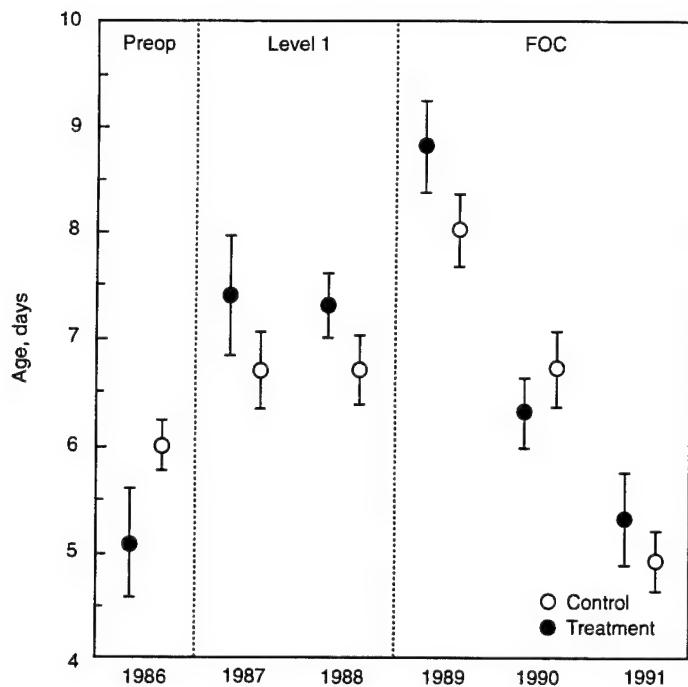


FIGURE 30. TREE SWALLOW AGE AT EYE OPENING (1986-1991).

ANOVA did not show any significant relationships between EM exposure and growth or development values.

Growth and developmental variables found significant in the site comparisons were not found to be significant in the gradient examination or transfer experiment. Although some statistical results suggested possible effects when isolated, investigators conclude that overall findings did not support an association between ELF EM exposure and the growth or maturation of swallows. Positive findings were attributed to unknown factors, possibly temporal and spatial disparities in meteorological factors.

Physiology. In addition to postulated direct effects, it has been speculated that EM fields adversely affect organisms by acting synergistically with other environmental factors. In the ELF System area, low temperatures make winter the most physiological stressful time of year. In order to examine for possible synergistic interactions, the aerobic metabolism of EM-exposed vertebrates was monitored as an indicator of their physiological health during winter.

Black-capped chickadees and deermice were collected during the winter along the NRTF-Republic's ROW and at a control site. Animals to be tested were held at an outdoor facility with food and water provided *ad libitum*. Tests for peak metabolism were performed in an ethanol-cooled chamber using a version of the helium-oxygen method. Test equipment was located at a laboratory in Crystal Falls, Michigan; the holding facility was situated several miles south of the city. Early experiments showed that the peak metabolic rates of deermice and chickadees did not change during three weeks of holding in the outdoor cages. After testing,

In order to more robustly test for potential short-term effects, a transfer experiment was also performed during 1990 and 1991. In this experiment, randomly selected nestlings were transferred within and between study sites. The variables examined were the same as those used in the (non-transfer) treatment and control comparisons. ANOVA found significant treatment effects for four of fifteen variables: body mass growth constant and inflection point, wing length growth constant, and age at eye opening.

Finally, because order-of-magnitude differences in EM fields existed between nest boxes at treatment sites (0-9 mG), growth and development data collected there were further examined to determine if there was a gradient or threshold response to EM exposure.

animals were released at their collection site. The metabolic rates of chickadees are addressed here, while rates for mice are presented in the following section (4.3.3) on mammals.

MSU investigators examined the data collected from 1985-1992 using ANCOVA. The dependent variable was the logarithm of whole-body peak metabolic rate; factors were site (treatment and control) and operation period (preoperation, intermittent operation, and full operation); and the covariate was the logarithm of body weight.

ANCOVA results showed small but significant differences in bird metabolism between sites and operational periods, but no significant site-by-period interaction. Peak metabolic rates generally declined over the term of the study; however, rates were consistently higher for birds captured on the control site. Since the intersite relationship did not change after the Michigan transmitter became fully operational, investigators conclude no ELF EM effects on adult metabolism.

Homing. Geomagnetic fields are used as cues in animal navigation, and ELF EM fields have been reported to slightly affect the orientation of birds. Any disturbance that affects orientation could affect an animal's ability to return to, or use, a home range and thereby decrease its probability of survival. Accordingly, the ability of vertebrates to return to their home range was monitored in the ELF System area by MSU researchers.

The homing of tree swallows, deermice, and chipmunks after displacement was examined from 1986-1993. The homing parameters were the likelihood to return (number of displaced individuals that return home) and, with swallows, the amount of time taken to return home. Bird homing is treated here, and mice and chipmunks in the mammal section (4.3.3).

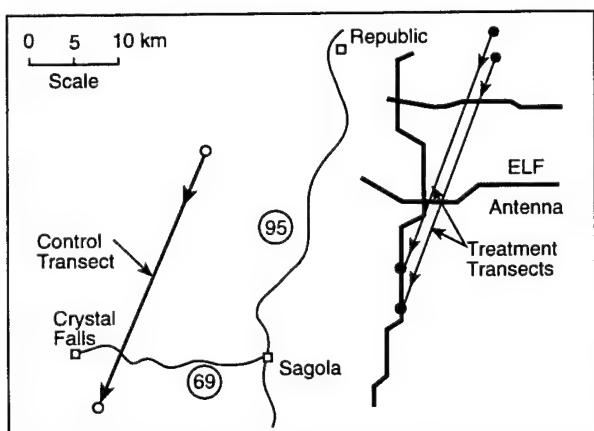


FIGURE 31. RETURN ROUTES FOR DISPLACED TREE SWALLOWS.

Adult birds from treatment and control sites were captured at nest boxes while brooding their young. Captured birds were banded, color-marked, and taken to release sites. The release points for 1986-1990 were located in open areas at a distance of 30 km from, and 20 degrees northeast of, the capture site. The direction of the (treatment) release points from the capture sites required birds returning to treatment sites to cross both EW antenna elements of the NRTF-Republic (Figure 31). Birds taken from a control sites were displaced at an angle and distance similar to that used for birds taken from the

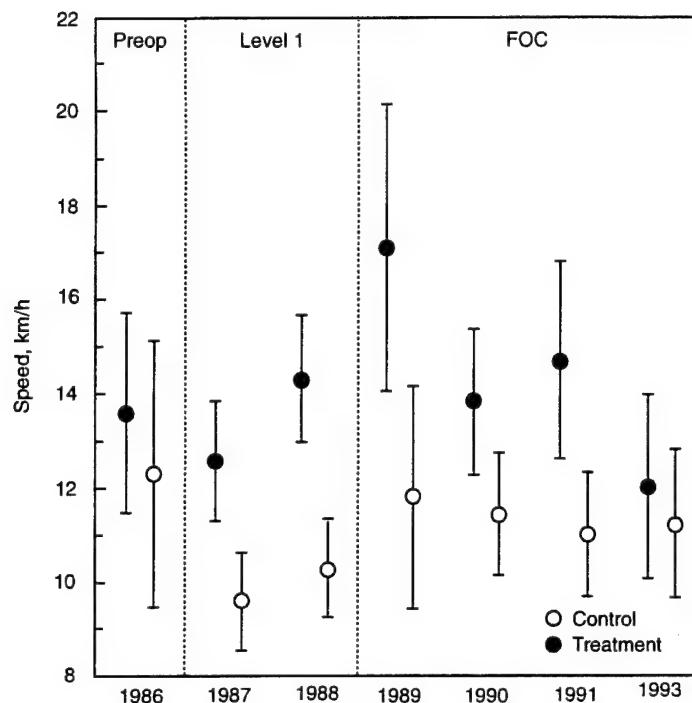


FIGURE 32. RETURN SPEEDS OF DISPLACED TREE SWALLOWS.

than birds returning to the control site. Homing studies were not conducted in 1992 due to severe weather effects on local bird populations; however, the 1991 protocol was used again in 1993. This time, there were no significant differences. Investigators conclude that the differences were not due to release points. ANOVA of all data 1986-1993 showed that birds captured at treatment sites were more likely to return, and return faster, than birds captured at control sites.

In order to more closely examine these results, investigators further examined the data for antenna energization parameters (amperes and on-off status) while displaced treatment site birds were in the air. Chi-square analyses indicated that 6 ampere energization of the antenna (on-off) had no effect on the speed of birds returning to the treatment site. ANOVA of 15 ampere energization suggested that displaced birds returned faster when the antenna was energized; however, the off condition was represented by only one day in each year (1987 and 1988). Finally, ANOVA of returning treatment and control birds when the antenna was energized, indicated a significant site-by-year interaction due to the convergence from relatively high return rates in birds captured at the treatment site in 1989 to rates similar to those for control birds in 1993.

Investigators conclude that significant differences in the homing performance of birds captured at treatment and control sites were not due to the ELF System because these differences were observed both prior to and during full operation of the Michigan transmitter. The gradual decrease in homing speed for treatment site birds during full operation of the antenna remains unexplained.

treatment sites; however, returning birds did not cross or come near any antenna elements. Observers located near the nest boxes recorded the time of return for the displaced birds.

Chi-square tests of data pooled over the 1986-1993 period showed that birds taken from treatment sites were more likely to return and came back faster than birds displaced from control sites (Figure 32). In order to examine the possibility that differences were due to release points, MSU researchers altered their protocols in 1991. In addition to freeing birds at the treatment release point, some treatment site birds were set free from the control release point. The mean speed of all birds returning to treatment site were significantly faster

Mortality. Chi-square contingency table analysis indicated that the likelihood of young to fledge was significantly different between sites in 1985, 1988, 1990, and 1991. Likelihood to fledge was significantly greater on the treatment site for three of these four years. During full operation of the Michigan transmitter, likelihood to fledge was significantly greater on the treatment site in 1990, and significantly greater at the control in 1991.

NANOVA did not demonstrate any effects on the number of fledged swallows per nest from operational conditions or site; nor was there any significant interaction between these factors. Significant yearly differences were associated with inclement weather during 1986, 1989, and 1992 which resulted in low numbers of fledglings at both treatment and control sites.

Investigators were 70 percent confident of detecting a 21 percent or greater difference between sites, or a 171 percent difference in operational periods, as significant for the success of fledglings. Year-to-year weather events had severely impacted survival of the young, making this parameter highly variable.

In order to take into account the duration of potential jeopardy to immature birds, investigators used a time unit of observation for comparison of EM exposure groups. Overall nest mortality was examined using nest-days. This was further broken down into incubation-phase nest mortality (period from egg laying to hatching) and young-phase nest mortality (period from hatching and fledgling). Egg-day and young-day parameters were also examined. Data were analyzed using chi-square contingency analysis, as well as maximum likelihood estimates and variances. Statistical results were markedly similar for each analytical method.

The general pattern that emerged from the analysis of all five parameters was that mortality was not clearly associated with the operational status of the Michigan transmitter. While there were 15 instances (42 percent) of higher mortality on treatment sites during intermittent and full operation of the transmitter, there were 19 instances (53 percent) when sites had equal mortality. There was no trend of significantly higher mortality at treatment sites across years; however, mortality was higher on treatment sites more often than on controls over the entire study period. Investigators were unable to draw a conclusion from the pattern of results.

Adult tree swallows had probabilities of annual survival from 0.2 to 0.8 per year. These rates did not differ between sites, nor operational periods of the Michigan transmitter. Estimated rates were highly variable but similar to those reported in the literature.

Populations and Communities. As indicated in the previous section, several bird species have been shown to sense and use geomagnetic fields to orient themselves. Thus, it has been suggested that birds may also be able to sense man-made EM fields and be attracted, repelled, or otherwise affected, by such sources. To determine if the EM fields produced by the ELF Communications System causes adverse effects to the bird community, investigators from UMD monitored birds living in, and migrating through, areas near ELF transmitters in Wisconsin and Michigan.

A line-transect method was used to census the bird community in the ELF System area. Two ornithologists simultaneously walked along a (randomly assigned) treatment or control transect to determine bird species and numbers from sightings and songs. From 1986 through 1993, the identification and enumeration of bird species was performed during each of five periods throughout the year: spring migration (May), early breeding (June), late breeding (July), early fall migration (August), and fall migration (September). In Wisconsin, studies were complete after the 1989 census, and in Michigan after the 1993 census.

As birds show a strong preference to habitat, the vegetation along transects was also characterized. In both states, control transects had more deciduous trees (aspen, birch, maple), while treatment transects were dominated by coniferous trees (black spruce, balsam fir).

Parameters derived from the census data were:

- total number of individuals (abundance)
- number of species (richness)
- number of individuals per common species.
- number of individuals per guild.

Differences between parameter values at treatment and control transects in Michigan were examined using ANOVA (repeated-analysis of measures). In Wisconsin both ANOVA and ANCOVA techniques were used. Covariate analyses employed detailed vegetation data collected during 1986 and 1987.

In Wisconsin 38,934 birds were counted (19,647 on treatments, 19,287 on controls) and 125 species identified. Eleven species were found only on Wisconsin treatment transects, and 12 exclusively on controls. A significant site-by-year interaction was found by ANOVA for the number of individuals in June. Total numbers were significantly higher on treatment sites during 1985 and 1986; however, numbers were nonsignificantly higher on controls thereafter. There were no significant site-by-year interactions for species richness.

In monitoring for possible EM effects in Wisconsin, it was important to determine whether differences were due to EM exposure or non-EM factors present on the study transects. This concern was addressed by guild analyses. Species that belong to the same guild share important biological characteristics such as food or vegetation preferences. All species of birds found on Wisconsin study sites were classified into guilds based on their foraging location and preferred breeding habitat. UMD investigators compared the total number of individuals for each of 10 guild types (5 foraging, 5 habitat) present on treatment and control transects in Wisconsin. ANOVA found no significant site (exposure)-by-year interactions, indicating that numbers of individuals on both treatment and control areas were responding to similar factors. Significant differences between transects based on preferred breeding habitats clearly reflected vegetation dissimilarities.

In order to examine for possible disparate reaction to ELF EM exposure among types of birds, the number of individuals per species was also examined. ANCOVA indicated site differences in the number of individuals for each of 38 bird species. Nineteen species had more individuals present on Wisconsin control transects (generally only one month per season), while thirteen species had more individuals on Wisconsin

treatment transects. Three species were more abundant on control transects one year and then were more abundant on the treatment transects in another year. There were no cases where site differences in abundance remained consistently significant across a season, and only one case where a site difference was consistent across the term of the study (1985-1989). Overall, ANCOVA results provided further support for treatment and control differences being related to habitat and not ELF EM exposure.

In Michigan 52,175 birds were counted (25,401 on treatments, 26,774 on controls) and 140 species identified. Five species were found restricted to treatment transects and 21 limited to controls. Site-restricted taxa were uncommon species that occurred at densities of less than one individual per transect.

ANOVA demonstrated a significant site-by-year interaction for both total number of individuals and number of species during fall migration (August, September). Investigators did not consider the interaction as resulting from operation of the Michigan ELF transmitter because the intersite relationship had changed several times, including the period prior to full operation (Figure 33). A significant site-by-year interaction also occurred for the number of species observed during the spring migration period (May). In this case, the number of species (and individuals) was consistently higher on control transects over the term of the study. There were no significant interactions for abundance or richness during the breeding season (Figure 34). Investigators concluded that these results did not indicate EM effects from operation of the Michigan transmitter.

In addition to the guilds used for analyses in Wisconsin, researchers also examined migration and nesting guilds in Michigan. There were relatively few significant site-by-year interactions in guild abundance

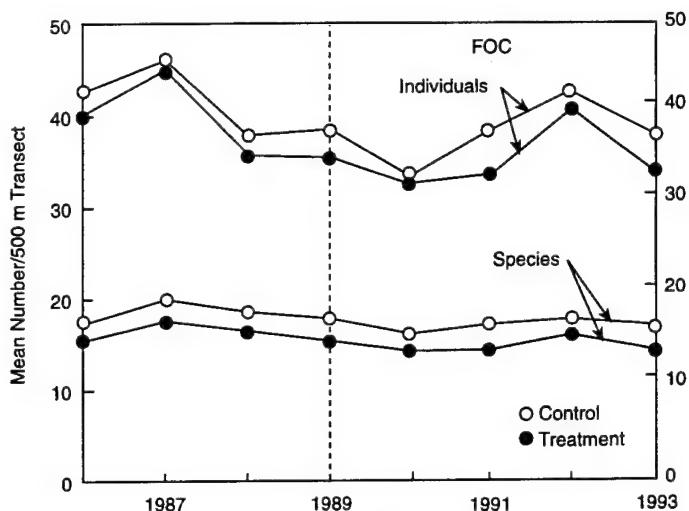


FIGURE 33. NUMBER OF BIRDS AND BIRD SPECIES OBSERVED IN MICHIGAN DURING SPRING MIGRATION (1986-1993).

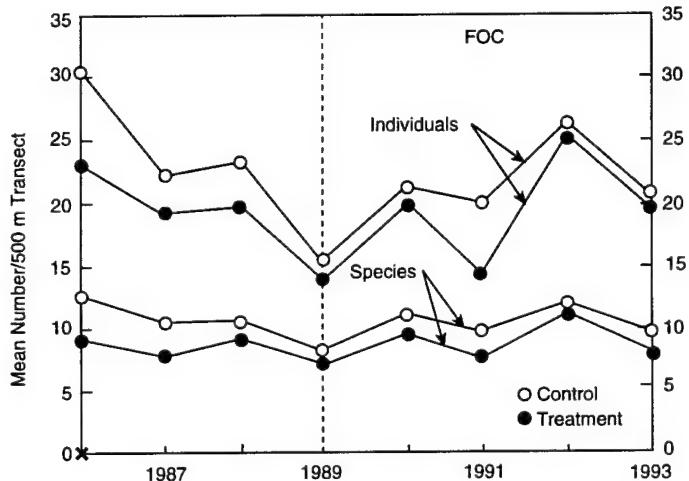


FIGURE 34. NUMBER OF BIRDS AND BIRD SPECIES OBSERVED IN MICHIGAN DURING BREEDING (1986-1993).

(8 out of 60, 13 percent). The pattern of results was not consistent across seasons, years, or sites, thus indicating that the results were random and not related to EM exposure.

Eight of the 125 species examined for their individual abundance (6 percent) showed significant site-by-year interactions. There were no cases where treatment and control differences remained significant across seasons. Yearly averages (1986-1993) showed no pattern relatable to antenna energization.

Overall, there was no consistent pattern of results that indicated changes in bird abundance from operation of the Wisconsin or Michigan transmitters. No significant interactions found at the community or species level were consistent across seasons. The number of significant interactions found at many levels of the analyses were not greater than the number expected by chance alone. Investigators conclude that the significant differences found were not attributable to ELF EM exposure.

4.3.3 Mammal Behavior, Biology, and Ecology

Along with their studies of birds, MSU researchers also monitored the growth, development, metabolism, and horning of deermice and chipmunks. Embryological aspects were not pursued because many reproductive females would have had to be sacrificed in order to examine their fetuses. Researchers estimated that removal of pregnant females in sufficient numbers to meet reasonable power in statistical testing would have been detrimental to local populations.

MSU studies were located on one treatment site immediately adjacent to the NRTF-Republic ROW (N/S antenna) and two control sites with habitats similar to the treatment sites. Control sites were located 12-18 miles west of the antenna and had cleared areas (sham ROWs) that were tended the same as antenna ROWs. One control and one treatment site consisted of a cluster of plots where studies of postnatal growth, adult physiology, and horning were performed. The other control was used exclusively for trapping purposes. As in the avian studies, investigators considered ELF EM exposures as preoperational during 1985 and 1986, intermediate in 1988 and 1989, and that representing a fully operational system from 1989 through 1993.

Growth and Development. The growth and development of deermice were monitored for the same reasons given for corresponding bird studies.

Large, open enclosures were used to restrict the movements of deermice during these studies. Each enclosure was equipped with a nest box, feeding station, and watering station. The deermice to be studied were captured in mixed deciduous forests near the enclosure sites. The animals were paired, and when the female was pregnant, she was transferred to the large enclosure to give birth and rear the young to weaning. Observations were then made while the young were located in a nest within the enclosure.

Early studies showed that growth curves of nestling body mass differed between litters. Therefore, rates were estimated using growth constants derived from linear regression analyses of each individual at the time of weaning. ANOVA indicated a significant site-by-year interaction for the constants. As the intersite relationship of the constants changed during both the intermittent and operational periods (Figure 35), the

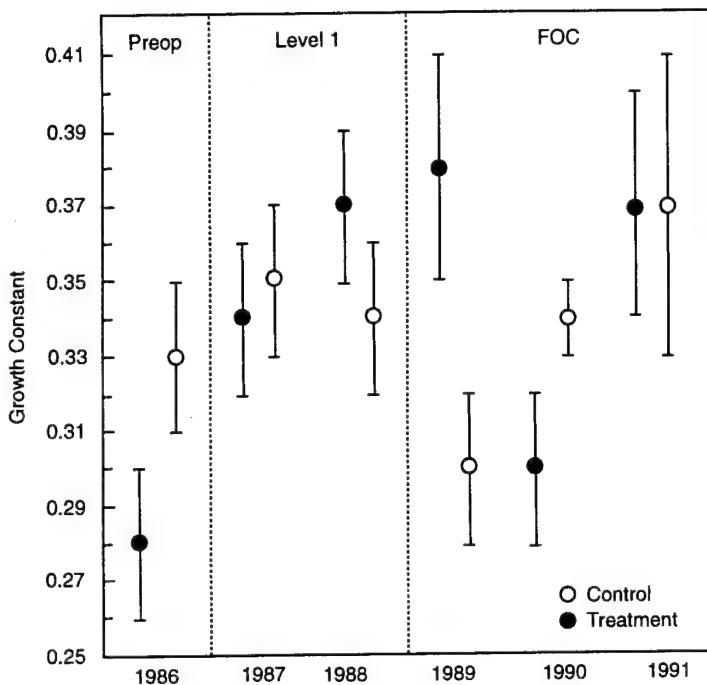


FIGURE 35. DEERMOUSE MASS GROWTH CONSTANTS (1986-1991).

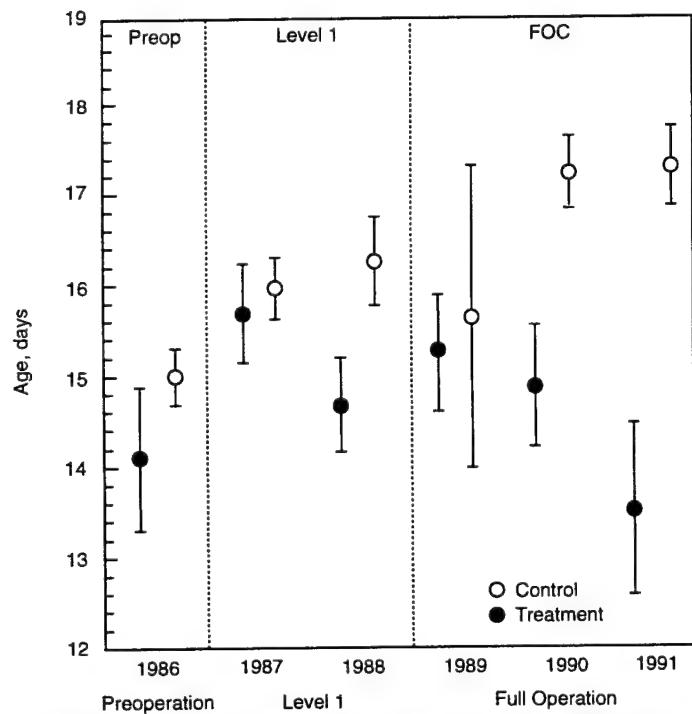


FIGURE 36. DEERMOUSE AGE AT EYE OPENING (1986-1991).

significant interaction was not considered as being related to transmitter operation.

ANOVA of developmental markers exhibited a significant site-by-year interaction for the age at eye opening but none for the age at incisor eruption. The interaction was due to a pattern of divergence between the sites (Figure 36). Age at eye opening increased at both sites from 1986 to 1987, thereafter diverging during the same period when the transmitter was at full operation. Investigators examined litter size as a possible factor in these results; however, none of their findings could explain the relative younger age for eye opening on the treatment plots.

A 28 percent difference in age at incisor eruption means would have been necessary to detect an operation effect with 70 percent confidence. Means for age at eye opening and body mass growth constants would only have had to differ by 7 percent and 12 percent, respectively, for a similar confidence level.

Physiology. See also the discussion of bird physiology (under Section 4.3.2).

Data on the peak metabolic rate of 150 deer mice were collected prior to (1985-1989) and during full operation (1990-1992) of the NRTF-Republic. Statistical comparisons of the rates were carried out using ANCOVA. The logarithm of the peak metabolic rate was used as the dependent variable and the logarithm of body weight as the covariate. As for the chickadees, there were no significant site-by-year interactions.

Metabolic rates of mice collected at treatment and control sites was initially different and remained so as values declined on both sites. The magnitude of the site difference did not change when the Michigan transmitter was first energized or later when the transmitter was fully operational. Investigators conclude no ELF EM effect on the metabolism of a representative mammal.

Homing. See also the discussion of bird homing (under Section 4.3.2).

Chipmunks and deermice were captured on a trapping grid at treatment and control sites. Displacements from their home range took place during, or just prior to, the next activity period following capture; deermice were displaced at dusk and chipmunks in the morning. Individuals were displaced either to the south or west of the trapping grid, with each animal displaced 450 m from the trap at which it was captured. The displacements to the south were through relatively continuous forest, whereas displacements to the west required the returning animals to cross the antenna ROW or sham ROW. Once an animal was displaced, traps on the grid were checked morning and evening for the next five days.

Possible ELF EM effects on homing were estimated by comparing each year's return frequency (1986-1993) on treatment and control sites using a chi-square test.

For chipmunks there were no site differences in likelihood to return, while for deermice site differences occurred in only two of the years. During 1989, a higher proportion of displaced mice returned on the treatment site; in 1990, a higher proportion returned on the control site. Although sample sizes were occasionally low during the term of the study, there were no indications that ELF EM exposure had any effect on the homing ability of these small mammals.

5. WETLAND STUDIES

In addition to upland and aquatic ecosystems, the ELF System area contains numerous wetlands. These areas support diverse food chains, provide wildlife resources, and—in many situations—regulate natural hydrologic systems.

Scientists had not previously investigated wetland biota for potential EM effects. Nonetheless, electric currents and magnetic fields are effectively transmitted through the water-saturated soils typically found in wetlands. The bioelectromagnetics literature indicates that cell membranes may be involved in biological interactions with ELF EM fields. A likely site of interaction could therefore have been the cell membranes in roots.

Investigators from the University of Wisconsin-Milwaukee (UWM) chose to monitor variables that could both be affected by altered root membrane function and, if changed significantly, influence processes important to wetland functioning. The variable selected for monitoring were foliar nutrients, water stress, and litter decomposition. UWM researchers also attempted study of nitrogen fixation but abandoned this variable upon finding that the results were too variable for discriminating small differences.

Eleven peat bogs, similar in plant community structure and groundwater chemistry were selected along an EM gradient near the NRTF-Clam Lake, Wisconsin. Study sites were placed into one of four exposure groups: antenna, ground, intermediate, and background. The antenna and ground sites (treatments) were located next to the transmitter elements they describe. The background sites (controls) were more than six miles from the nearest transmitter element, and had an EM intensity 100 times less than the treatment sites. Investigators located intermediate sites to have EM intensities between those of the treatment and control.

Environmental, EM, and biological variables were measured at six locales with each study site. Environmental variables were determined monthly during the growing season (May-September) from 1983 through 1987, while biological samples were collected according to sampling protocols established for each. The investigators examined dominant tree, shrub, and herb species common to all study sites.

Data were analyzed using a nested ANOVA with replicate bogs within each EM exposure group. Multiple regression and canonical correlation were used to account for the variance in biological variables using environmental factors and EM exposures. Each sampling period and each variable were analyzed independently.

5.1 Vegetation: Herb, Shrub, and Tree Physiology

Cations (Ca, Mg, K, and Mn) and phosphorus (P) are important constituents in many biochemical reaction pathways. As in agricultural and horticultural studies, the UWM researchers chemically analyzed foliage to ascertain the nutritional state of abundant plant species found in bogs near the Wisconsin transmitter. After developing protocols, the research team monitored the nutrient content of herb, shrub, and tree foliage from 1985 to 1987.

Five significant differences between exposure groups were detected in 79 separate ANOVAs. Except for manganese concentrations in herbaceous foliage, there was no pattern of significant results relatable to EM exposure. In the case of manganese, intermediate and ground site concentrations differed from those determined for control site herbs during June and July of 1986. There was, however, no significant difference between antenna and control site values for the same period. Additional analyses using multiple regression and canonical correlation indicated that EM exposure could potentially account for only a small percentage of the variation in the nutrient data.

Investigators reason that the number of significant differences detected occurred at a frequency that could be expected by chance alone. They concluded no ELF EM effects on foliage nutrient concentrations. Investigators did not report the power of their statistical tests; however, coefficients of variability across species and nutrients ranged between 6-55 percent. The coefficients were, on the average, less than 19 percent.

EM effects on cell membranes could also cause plant stress by affecting either water uptake through osmosis or operation of leaf stomata by impairing transpiration. In order to monitor for possible water stress, UWM researchers used a null-balance, diffusive resistance porometer to measure the rate of vapor diffusion from shrub leaves. After examining several plant species and developing measurement protocols, researchers measured diffusion rates of Labrador tea leaves during measurement periods (several days) in July and August of both 1986 (30 individuals/site) and 1987 (60 individuals/site). Covariates were needed to account for changes in environmental conditions between measurement periods.

Nested ANOVA and multiple regression analyses produced differing results. ANOVA indicated one statistically significant EM treatment effect (July 1987) among the four study periods. However, multiple regression of the July 1987 data selected time of measurement, light intensity, temperature, but not ELF EM exposure as important sources of variability. EM exposure was, however, selected by regressions as an important variable in two other data sets. During July 1986, EM exposure had an apparent positive influence on diffusion, whereas during August 1987 exposure had an apparent negative influence.

UWM researchers concluded that the water stress results had no relationship to ELF EM exposure. Coefficients of variability for diffusion data ranged between 9 and 32 percent and, on the average, were less than 16 percent.

5.2 Decomposition: Litter and Cellulose Breakdown

Decomposition of organic material is an important community level process occurring in all natural systems. Low total amounts of organic turnover is characteristic of northern peatlands, and the decomposition rate is a major factor regulating the formation of each bog.

Investigators initially used cellulose wood pulp, and then later the leaves of Labrador tea, as organic substrates in monitoring decomposition processes. Over the course of study, 48 to 96 samples were annually placed on the bog surface. The samples were retrieved and reweighed after being emplaced for periods of 4, 8, or 12 months. A series of seven studies were performed from October 1983 through October 1987.

ANCOVA did not demonstrate any significant differences between exposure groups for six of seven studies. The analysis of 1987 data did, however, detect a significant difference. An Unplanned Comparison of Means Test for the 1987 data indicated that Labrador tea leaves at the antenna bogs lost more weight than the other three exposure regimes (Figure 37). However, a stepwise regression procedure did not select EM exposure as a factor important in explaining the 1987 weight loss. Supplemental examination suggests that the greater weight loss at the antenna bogs were due to moss overgrowth of the litter bags. More litter bags were covered by moss at the antenna sites (62 percent) than at the other sites (25-35 percent).

Based on the inconsistent nature of the results, investigators concluded no association between decomposition rates and EM exposure. UWM investigators could not account for much of the variance in decomposition. They were able to explain only 30-35 percent of the variance in cellulose breakdown and 32 percent of the variance in Labrador tea.

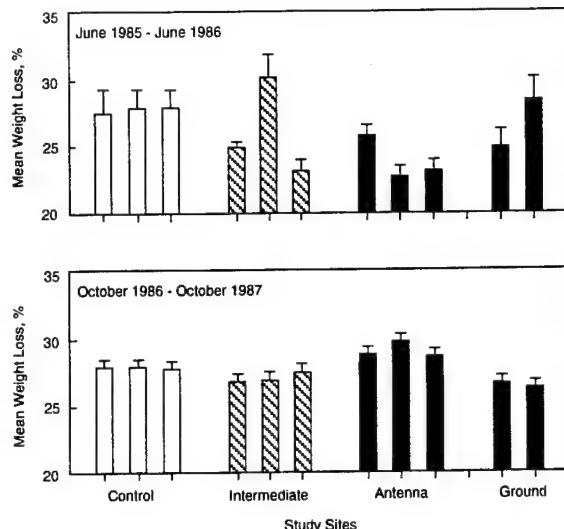


FIGURE 37. ANNUAL DECOMPOSITION OF LABRADOR TEA FOLIAGE IN PEAT BOGS (1985-1987).

6. FRESHWATER STUDIES

Aquatic habitats in the ELF System area include freshwater lakes, and rivers that drain into the Mississippi River or the Great Lakes. Although these habitats occupy a relatively small portion of the ELF System area, they are important recreational resources. Streams are used by migratory fish and are important for their spawning. Lower trophic levels such as algae and invertebrates support fish biomass, and are of intrinsic interest as potential indicators of bioelectromagnetic effects.

The NAS concluded that some species of freshwater fish could detect Seafarer fields (70 mV/m), but they expressed uncertainty regarding the effects of such fields on normal fish behavior [5]. It has been reported in the literature that other aquatic biota (bacteria and diatoms) or their terrestrial counterparts (insects), also use or react to weak EM fields. Like soil organisms, aquatic biota are closely coupled to electric fields produced in the water.

The potential effects of the ELF System on stream ecosystems were examined using a before-after, control-impact (BACI), paired plot design on sections of the Ford River, a fourth-order trout stream in Dickinson County, Michigan. MSU researchers selected a river as a representative aquatic ecosystem in part to examine migratory behavior, and in part because paired plots on the same river were likely to have less parameter variability than those for paired lakes.

During 1983-1993, researchers monitored periphyton, aquatic insects, and fish communities present on similar sections of the Ford River. They also measured natural environmental factors such as river discharge, temperature, and nutrients at the study sites. Treatment sites were located adjacent to the NS leg of the NRTF-Republic, while downstream control sites were located more than 8 km from the antenna. Statistical analyses demonstrated that treatment and control sites were relatively well matched for non-EM environmental factors.

6.1 Procedures: Periphyton Ecology

Periphyton are part of a community of microscopic plants and animals associated with the surfaces of submerged objects. Unlike organisms suspended in the water column, the community's characteristics at a given location are governed by conditions at that point. Because periphyton are important primary producers, possibly affected by EM fields, and indicative of conditions at the antenna crossing, their characteristics were monitored for possible EM effects.

Researchers placed glass slides of known surface area into the Ford River to allow periphyton to colonize them. The slides were periodically removed and analyzed in order to determine structural and functional characteristics of the colonizing biota. To minimize errors associated with a single method approach, investigators collected multiple independent sets of data and later analyzed them by several statistical techniques. The periphyton established on the glass slides were representative of the community found on natural substrates.

For the purpose of statistical analyses, investigators divided yearly data into seasons and temporal regimes of EM exposure. The latter periods were:

- preoperational - April 1984 to October 1985
- transitional - April 1986 to May 1989
- operational - June 1989 to August 1993.

Statistical comparisons emphasized BACI techniques. The before and after data correspond to measurements made during the ice-free seasons for preoperational and operational periods, respectively. Data collected in the transitional period were not included in the BACI analyses. Randomized intervention analysis (RIA) was used for the same analysis when BACI techniques were not appropriate. Researchers also calculated a correlation matrix for all ambient and biological/ecological variables.

Since the periphyton community was dominated by diatoms, their identification and enumeration were emphasized. This approach allowed detection of possible shifts in the relative abundance of dominant species and the community makeup through calculations of evenness and diversity indices. The cell volume of dominant diatom species was also determined as an indicator of their physiological state.

Although temporal changes in many structural variables occurred between before and after periods (e.g., Figure 38), BACI analyses indicated that they were not statistically significant. Based on these results, investigators concluded that operation of the Michigan transmitter had no effects on either the physiological state of dominant diatoms or the basic structure of the diatom community. Other statistical tests showed that the BACI analyses provided a high probability of detecting small differences in intersite relationships for these structural variables.

Because numbers and types do not necessarily provide a complete characterization, investigators also monitored the following functional aspects of the periphyton community:

- community production and respiration
- dominant diatom biovolume

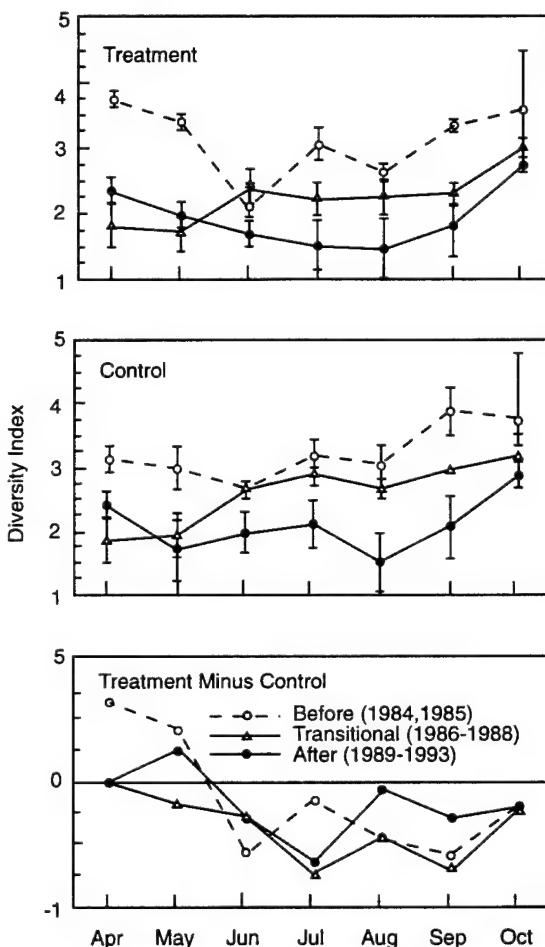


FIGURE 38. SPECIES DIVERSITY OF DIATOMS IN THE HEADWATERS OF THE FORD RIVER, MICHIGAN (1984-1993).

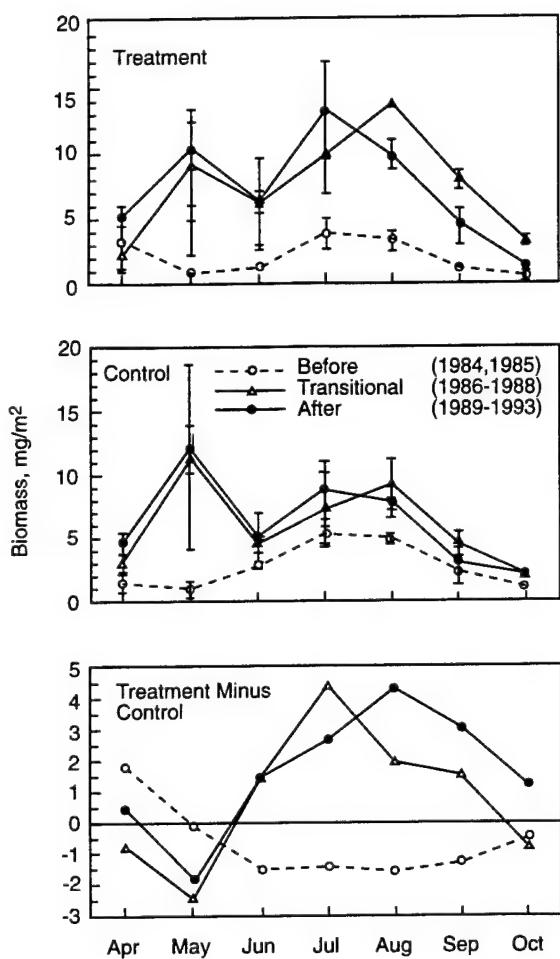


FIGURE 39. CHLOROPHYLL BIOMASS IN THE HEAD WATERS OF THE FORD RIVER, MICHIGAN (1984-1993).

- overall diatom density
- chlorophyll standing crop and accrual rates
- organic matter standing crop and accrual rates.

BACI analyses did not demonstrate significant changes between preoperational (1984-1985) and operational periods (1989-1993) in the intersite relationship of community photosynthesis and respiration, diatom biovolume, or diatom density. Similar comparisons indicated significant differences in other measures of productivity (i.e., chlorophyll and organic matter standing crop, and their accrual rates).

Investigators note that chlorophyll standing crop best reflected the change in site relationships and that changes in this parameter occurred during 1986, the first year of low-amperage, intermittent testing of the antenna. Prior to 1986, average seasonal chlorophyll (Figure 39) and organic matter biomass was larger at the control site than at the treatment site. Subsequently, the seasonal average changed so that treatment site biomass was larger. The change had resulted from an increase in the number of occurrences when the treatment site biomass was larger (from 30 percent to 70 percent). MSU investigators propose that standing crop and accrual data resulted from EM stimulation of algae, particularly during the *Cocconeis placentula*-dominant period from June to September.

Intermittent low-power testing of the Michigan antenna began during 1986 as did a prolonged period of lower rainfall (Figure 18) and higher temperatures (Figures 16 and 17) than experienced in previous years. Beginning in 1986, both treatment and control sites underwent important, but near identical, changes in seasonal pattern (Figure 39). A previously absent spring peak in biomass appeared and summer peaks became more pronounced. If the change in chlorophyll is related to ELF EM exposure, the data would suggest a threshold between 45 and 310 μ G (1.2 -2.5 mV/m) at the treatment site and perhaps field intensities ten times lower since control values also changed. As the antenna was operated only 1.2 percent of the study period in 1986, time-weighted averages would place these putative magnetic field thresholds 100 times lower.

Correlation matrices showed that water temperature and velocity were related to chlorophyll and organic matter standing crop data. In stepwise multiple regressions, water temperature, discharge, and

nitrogen explained most of the variance in the preoperational data. The regression model failed to fit EM exposures to chlorophyll or organic matter biomass data. Neither earth electric fields nor magnetic flux densities accounted for any of the variance in other periphyton data at the treatment site during operation of the ELF antenna.

Investigators conclude that either some unmeasured parameter or ELF EM exposure caused the biomass increases at the antenna site. They deduce that increases in chlorophyll and organic matter were related neither to biological interactions nor to differential responses to changes in average physicochemical factors. As such, an ELF EM effect seemed most plausible to them.

Nevertheless, the question remains as to whether it is more plausible that the changes in site relationships are coincidental to initial energization of the antenna or that they are more appropriately attributed to ELF EM exposure. BACI analyses cannot establish cause and effect but only changes in the relationship between sites. Further statistical analyses failed to link EM exposures to periphyton parameters. Correlations and regression did, however, establish associations between periphyton parameters and ambient physicochemical conditions.

6.2 Primary and Secondary Consumers

Aquatic insects were monitored because they are important primary and secondary consumers in the aquatic food chain. Investigators examined structural and functional aspects of the community colonizing benthic substrates and packs of leaf litter. They also monitored for possible EM effects on orientation by studying the movement of dragonfly naiads.

6.2.1 Benthic Insect Ecology

The purpose of these studies was to determine if ELF EM fields affected aquatic insects in stream benthos. Ten years (1984-1993) of data on insect community fluctuations were collected and related to mean discharge, water temperature, and ELF electric ground fields.

Sample baskets containing river substrates were emplaced at study sites for one-month periods. The baskets were retrieved; investigators separated the colonizing insects from the substrates; they then identified and counted the specimens. Data for ecological parameters were sorted into seasonal categories: spring (April, May), summer (June-August), and fall (September-November). Numbers of individuals (without chironomids), diversity, richness, evenness, and percent numerical dominance for chironomids were used to characterize important structural parameters of the community. Total insect mass, percent mass dominance of chironomids, collector-gatherer mass dominance, and predator-prey ratios defined important functional aspects of the community.

ANOVA tests were used to examine temporal and spatial community indices. Comparison of preoperational (1984-1986) and operational (1989-1993) data was accomplished by using BACI or RIA. Multiple linear regression was used to assess the relative contributions of physicochemical factors to parameter variation.

BACI and RIA revealed significant preoperational versus operational differences for five of 27 comparisons (9 parameters \times 3 seasons):

- numbers of individuals (summer, fall)
- chironomid numerical dominance (spring, fall).
- total insect mass (summer)

Numbers of individuals and chironomid numerical dominance were highly variable parameters. Neither environmental factors nor ELF ground electric fields accounted for meaningful amounts of variability in these parameters.

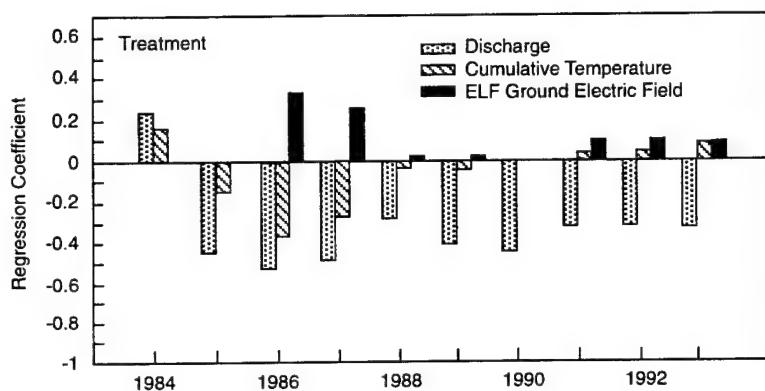


FIGURE 40. RELATIONSHIP OF INSECT MASS TO EM AND NON-EM FACTORS DURING MICHIGAN SUMMERS (1984-1993).

The intersite relationship of summer insect mass also changed after the Michigan antenna was fully energized. However, relatively larger changes in insect mass at the control site after 1989 appears to be the reason for this significant change. Sequential multiple regression of total insect biomass at the antenna site showed that biomass variability was primarily associated with differences in river discharge and not to ELF ground field exposures

(Figure 40). There were no significant differences in total insect mass site relationships in the spring and fall.

The effects of a grazing benthic insect, *Glossosoma nigrior* on diatom community structure were also examined by MSU investigators. No EM effects on grazer cropping of chlorophyll or AFDW biomass were indicated. Results were inconsistent across years. Investigators considered the data to be too variable for detecting ELF EM effects, and studies were concluded at the end of the 1989 season.

Investigators concluded that the data did not demonstrate an ELF EM effect on the benthic community.

6.2.2 Leaf-pack Insect Ecology

In headwaters such as exist in the ELF Communications System area, only a portion of the energy input to the river is provided by periphyton. Leaves from riparian vegetation are caught in snags and are then colonized by aquatic fauna, mainly insects. The colonizing insects form a distinct community using the leaves as their energy source. In doing so, the colonists make their biomass generally available to other insect predators and fish in the stream.

A "leaf pack" bioassay technique was used to monitor for possible EM effects to this aspect of the aquatic community. Fresh leaves were collected from a tag alder grove adjacent to the Ford River. Leaves were weighed, tied to bricks in packs, and placed at study sites. After 28 days, the leaf packs were retrieved.

Insects colonizing the packs were identified, enumerated, and the loss in leaf mass determined. These data were then used to characterize structural and functional parameters of the processing community.

Data collected over a nine-year period (1984-1992) were analyzed using ANOVA or t-tests, and multiple regression. BACI tests could not be performed because samples were not independent of emplacement date.

Structural parameters included number of individuals, percent chironomid dominance, evenness, diversity, and richness. As expected, all parameters showed some statistically significant differences between years; however, only diversity and richness showed significant site-by-year interactions.

Taxon diversity was higher at the control site only in 1985 (preoperational year) and 1991 (fully operational year). Taxon richness values were dissimilar at the two sites until 1988, after which time the values at the two sites were similar. These across-year patterns did not match ELF EM exposure milestones. Multiple linear regressions indicated that the structural characteristics of the leaf pack community were primarily related to cumulative degree days and, to a lesser extent, river discharge. Researchers conclude that ELF EM exposure was not the apparent cause of the significant interaction terms.

ANOVA was used to scrutinize functional community parameters of organisms colonizing leaf packs. The parameters included leaf processing rates, total insect biomass (adjusted to leaf biomass), and the mean (dry) weight per individual for three abundant insect species.

Generally, leaf processing rates were not significantly different between the treatment and control sites. Processing rates differed between sites only in 1985 and 1990. In 1985 (preoperational year) leaf processing rates were faster at the treatment site, whereas in 1990 they were faster at the control site. Regression results suggest that treatment site rates were related to river discharge but not EM exposure.

ANOVA showed significant differences in insect biomass between years but not between sites or in site-by-year interactions. Biomass values generally increased slightly until 1988 when they increased markedly at both sites (Figure 41). Exceedingly high biomass at the treatment site in 1991 was due to some very large stoneflies on two of the seven leaf packs. Results fail to correlate with EM exposure; however, due to the high variability in values, investigators considered this parameter to be relatively insensitive.

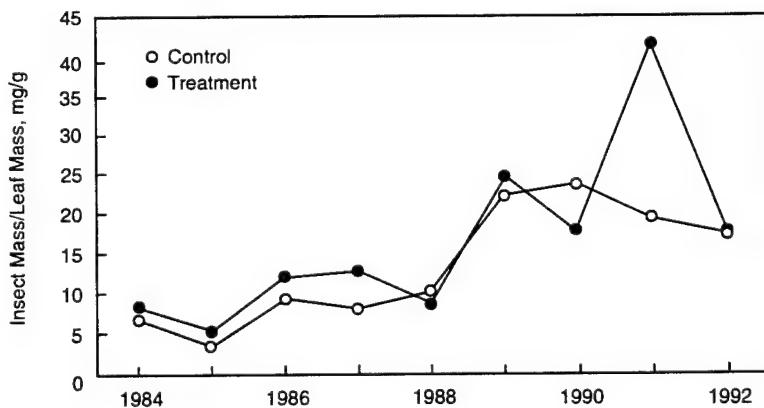


FIGURE 41. AVERAGE ANNUAL INSECT MASS RELATIVE TO LEAF MASS AFTER FOUR WEEKS EMBLENTATION IN THE FORD RIVER, MICHIGAN (1984-1992).

If ELF EM exposure alters growth, effects should be apparent in growth rates and/or in maximum size at emergence. To assess this, investigators monitored three insect species commonly found on the leaf packs that also grew in the spring and fall. ANCOVA showed no significant differences between sites over time for two of the three species. In the case of the third species, the intersite relationship changed several times over the course of the study. Because the pattern of change did not correspond to activation or full powering of the ELF System, investigators concluded no ELF EM effect.

6.2.3 Naiad Movement Behavior

Other studies have shown that DC and ELF EM fields can affect orientation behavior of terrestrial counterparts. Since aquatic insects often use drift in response to stress conditions and otherwise have orientation needs, movement behavior was used to test for possible effects from the operation of the ELF System.

Mark-and-recapture techniques were used to discern the movement patterns of displaced dragonfly naiads, *Ophiogomphus colubrinus*, over the period 1985-1989. Student t-tests and multiple linear regression showed that the mean distances moved by the naiads were not related to ELF EM exposure but were strongly associated with river discharge.

MSU investigators conclude that the movement of dragonfly naiads was not affected by intermittent exposure to low-intensity ELF EM fields.

6.3 Tertiary Consumers

Some species of fish have an ability to perceive extremely small EM fields, including intensities produced by the ELF System in the Ford River. The fish can use their perceptive ability to both orient themselves and detect prey. Fish might therefore be directly affected by ELF EM exposure. As tertiary consumers, they could also be indirectly affected by EM-caused changes at lower trophic levels. Accordingly, structural and functional aspects of the fish community as well as their movement characteristics were monitored by MSU researchers for possible effects from operation of the ELF Communications System in Michigan.

The fish community was sampled by deploying two fyke nets (one facing upstream and another facing downstream) at each of three sites. Nets were located at a downstream control, near but downstream the NS antenna crossing (treatment), and 400 m upstream of the treatment site (treatment). Additional net sites on the upper Ford River and Two Mile Creek were used prior to 1991 to follow fish movements beyond the ELF System area.

Netted fish were identified, counted, weighed, and measured for length. Common species had their fins clipped for identification. The fish were then released in the original direction of travel, i.e., either upstream or downstream of the capturing net. Community parameters determined from these samples were the species composition and the abundance of common species by numbers and biomass. Several individual species

were also evaluated for stress by comparing them to literature-derived age and growth data. Movement rates of trout were determined by the distance between nets and the period between captures.

Data were divided into three periods for statistical analyses:

- preoperational (1983-1985)
- intermittent (1986-1988)
- operational (1989-1993).

Analyses were performed using ANOVA, chi-square, Spearman Rank Correlation, or BACI statistical techniques.

6.3.1 Fish Ecology

The fish community at treatment and control sites remained similar throughout the study. Over the term of the study, 29 species were netted at the control and 24 species were collected at the treatment site. This slight differences in species richness between sites resulted from occasional catches of uncommon species at the control. Species richness was greater at the control site in all years except 1987 and 1993.

Investigators found no significant differences between sites or operational periods for fish species diversity; however, diversity steadily decreased at both sites since initiating studies in 1983. Since species richness did not decline in a similar fashion, investigators conclude that the Ford River fish community has become progressively dominated by fewer species.

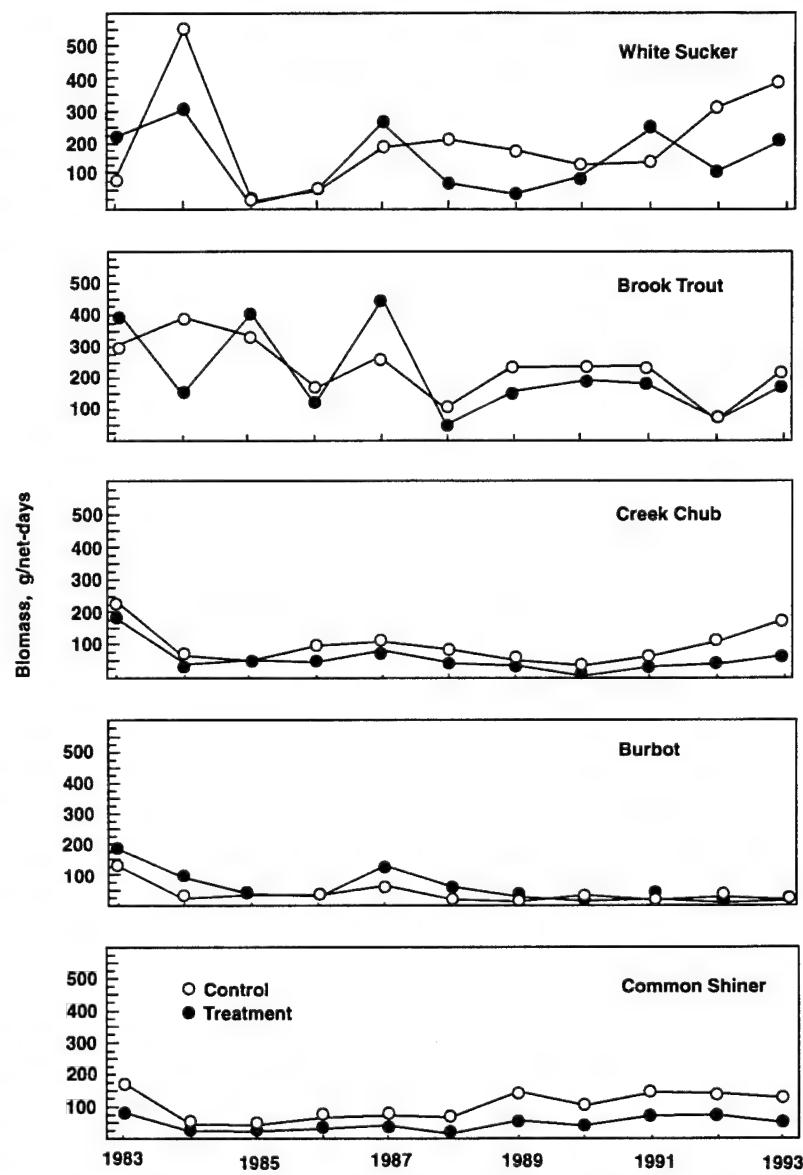


FIGURE 42. RELATIVE BIOMASS OF DOMINANT FISH IN THE FORD RIVER, MICHIGAN (1993-1993).

Numerically, and by biomass, the fish community at both sites was dominated by the same five species over the term of the study (Figure 42). The dominant species were brook trout, white sucker, burbot, common shiner, and creek chub. BACI analyses showed no significant differences in the preoperational-operational biomass for any of the dominant species. Total fish biomass declined from 1983 through 1986, then gradually increased until 1993 when biomass at the control returned to 1983 levels. Total fish biomass at the treatment site showed a similar, but more variable, pattern relative to that at the control site.

In general, the growth patterns of brook trout captured at treatment and control sites were similar throughout the period of study. Analysis indicated that brook trout in the Ford River exhibited average or better growth-at-age than that reported in the literature. Tukey-Kramer Multiple Comparison testing showed trout growth to be similar between preoperational and intermittent testing periods. Growth during the operation period was significantly larger than that experienced in the other two periods. Other data indicate that the age and size structure of brook trout was related to late spring and early summer water temperature of the Ford River.

Relative weights of common shiners, creek chubs, and white suckers were also used as indicators of possible stress to the fish community. Graphic analysis of data collected since 1983 pooled over both treatment and control sites showed that the relative weights of common shiners and creek chubs were above literature means. Throughout the study, the relative weight of white suckers has remained more than 10 percent below the species means for other white sucker populations reported in the literature. This below-normal condition existed prior to intermittent or full energization of the antenna.

There were no significant differences between sites or operational periods for species diversity, biomass, or condition; no common species disappeared, and no rare species became common. Investigators conclude no measurable effects to the fish community of the Ford River from intermittent or full operation of the Michigan transmitter.

6.3.2 Fish Movement Behavior

Most non-salmonid fish (burbot, shiner, chub, and sucker) were recaptured at the site of their initial tagging. However, a number of each species were recaptured at other sites, demonstrating their upstream and downstream movement under the antenna.

Low movement patterns correspond to beaver dams and low river flows experienced from 1986 through 1990. The dams were destroyed by high spring flows occurring in the spring of 1991. The number of fish recaptures during 1991-1993 was substantially greater than those in the previous eight years; during the last three years the number of fish moving across the antenna ROW was about three times greater than non-passing fish.

The brook trout, an important sport fish, was also monitored for pattern, rate, and magnitude of movement. The general pattern of trout migration was upstream one through the ELF Communications

System area in about the same proportions as non-salmonid fish. Factors affecting the distribution pattern and timing of peak catches were best related to water temperature, river discharge, and trout population size.

Catch statistics indicated fish community mixing over distances greater than the distances between sampling sites. Because of this, researchers note that accurate estimates of EM exposure were not possible and that only large-scale changes would have been detectable. Nevertheless, all representative species have demonstrated both upstream and downstream movement beneath the ELF antenna whether it was operating or not. Investigators conclude no ELF EM effects on fish movement.

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APPENDIX A

LIST OF PROGRAM PUBLICATIONS AND PRESENTATIONS (1982-1995)

LIST OF PROGRAM PUBLICATIONS AND PRESENTATIONS (1982-1995)

Final Reports, Compilations, and Symposia (Subcontractors/IIT Research Institute)

1. Band, R.N. ELF Communications System Ecological Monitoring Program: Soil Amoeba Studies—Final Report. IIT Research Institute, Technical Report D06214-1, 182 pp., 1995.
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APPENDIX B

STATEMENT OF WORK AND PROGRAM SUMMARY (1982-1995)

ATTACHMENT I

SOLICITATION NO. IITRI-E06516-82-R-0015

**ELF COMMUNICATIONS PROGRAM
ENVIRONMENTAL PROTECTION PLAN**

STATEMENT OF WORK

ECOLOGICAL MONITORING PROGRAM

18 MARCH 1982

**ELF COMMUNICATIONS PROGRAM
ENVIRONMENTAL PROTECTION PLAN
ECOLOGICAL MONITORING PROGRAM**

1. PURPOSE

1.1 Scope

The purpose of this work is to determine if low-level, long-term electromagnetic fields and gradients produced by an ELF Communications System affect vegetation and/or wildlife located in and near the system area. The scope of desired studies includes multi-year investigations of ecological compartments of forest environments in the Chequamegon National Forest in northwestern Wisconsin and in the contiguous Michigamme, Escanaba and Ford River State Forests in the Upper Peninsula of Michigan. Post-construction investigations are possible in Wisconsin. Both pre-construction and post-construction studies are desired in Michigan.

2. DEFINITIONS

The following definitions apply for this work:

ELF Communications System. The transmitter station and peripheral electrical equipment, the transmitter control center and peripheral electrical equipment, antenna cables, ground terminals and feed lines.

System Area. A two-mile boundary extending for one mile on either side of antennas, feed lines and ground terminals, at which boundary electrical fields produced in soil by the ELF Communications System have decreased by approximately one order of magnitude or more relative to values on the surface of the earth directly below an overhead antenna. The system area in Wisconsin is identified in Figures 3, 4, 5 and 6 of Exhibit A. The system area in Michigan will be identified precisely at a later date, and will be within the perimeter of the contiguous Michigamme, Escanaba River and Ford River State Forests depicted in Figure 9 of Exhibit A.

Subcontractors. Individuals and/or organizations selected to perform tasks proposed and approved within the scope of this statement of work.

Subcontract Administrator. The person representing IIT Research Institute (IITRI) authorizing contractors to perform this work.

Program Coordinator. The person authorized by IITRI to provide technical direction to contractors.

3. APPLICABLE DOCUMENTS

Exhibit A. Extremely Low Frequency (ELF) Communications Program in Wisconsin and Michigan; System and Site Definition, Program Plans, Environmental Summary and Supplemental Information; Naval Electronic Systems Command; December 1981;

Exhibit B. Biologic. Effects of Electric and Magnetic Fields Associated with Proposed Project SEAFARER; Committee on Biosphere Effects of Extremely Low Frequency Radiation, Assembly of Life Sciences, The National Research Council, National Academy of Sciences; 1977 (pp. 27-54).

Exhibit C. Ecology; From SEAFARER ELF Communications System Draft Environmental Impact Statement for Site Selection and Test Operations; Appendix E, Biological and Ecological Information; Naval Electronic Systems Command; February 1977 (pp. A-96-A-112).

Exhibit D. Pilot Survey of Small Mammal Populations in the Chequamegon National Forest during 1971 and 1972; IIT Research Institute Technical Report E6357-4 to Naval Electronic Systems Command; August 1976 (pp. 1-37).

4. STATEMENT OF WORK

4.1 General Requirements

Subcontractors shall develop ecological monitoring programs to be initiated on or about 1 July 1982 and continued for a period of 28 months in Wisconsin (31 October 1984 end date) and/or a period of 52 months in Michigan (31 October 1986 end date). Ecological monitoring may continue beyond these end dates through contract renewals or new solicitations.

Subcontractors shall provide all materials, work spaces, analytical tools, and technical and administrative support services necessary to satisfy the requirements of this statement of work. IITRI-furnished materials and information are limited to Exhibits A through D contained herein except for meeting facilities which may be provided by IITRI periodically, electromagnetic field intensity information (a subcontractor option), related ELF Program information, and MSK modulators, if required.

Subcontractors are responsible for obtaining rights-of-entry from cognizant forest managers in order to perform studies proposed within the scope of this statement of work. The cognizant agency in Wisconsin is the U.S. Forest Service, and the Department of Natural Resources is the responsible agency for managing state forests in Michigan.

Subcontractors must coordinate selection of study areas with cognizant government agencies. Arrangements with property owners are the responsibility of subcontractors in the event locations on private

land are selected for studies. Monitoring activities must not damage forest resources. Methods for protecting study areas from intrusion require the prior approval of land managers. Living accommodations on public lands also require prior approval of land managers. Subcontractors will be responsible for inadvertent site damage, restoration and clean-up following studies.

4.2 Program Options

Subcontractors may propose and afterward periodically recommend alternatives to program elements included in this statement of work. Subcontractors must demonstrate that alternatives are scientifically sound, are statistically meaningful, and preferable for discerning whether electromagnetic fields produced in the system area by the ELF Communications System affect flora or fauna. Subcontractors may not implement proposed alternatives and cannot terminate established program elements until authorized in writing by the Subcontract Administrator.

Proposed alternatives may include research conducted in laboratories to support studies conducted in the field. Subcontractors are required to account for appropriate test, ambient and electromagnetic monitoring in proposals including laboratory research.

Subcontractors are responsible for designing, fabricating, testing, evaluating and operating equipment used to generate ELF electromagnetic fields for laboratory research, except that IITRI will provide equipment necessary to simulate ELF Communications System modulation characteristics. IITRI reserves the right to determine by independent measurements that electromagnetic fields produced in laboratory arrangements conform to design requirements. Preliminary electromagnetic design information must accompany proposals.

Subcontractors may elect to conduct all work or only selected portions of work included in this statement. Each proposed work element or alternative will be evaluated independently in selecting subcontractors. Subcontractors are encouraged to group specific tasks into logical sets where such groupings would enhance interpretation of clearly related data. Direct costs of each proposed work element or related sets of work elements are required, and funding may be limited to approved work elements.

4.3 General Design

The Ecological Monitoring Program is intended to determine whether electromagnetic fields produced by the ELF Communications System influence plant and/or animal populations, or otherwise result in community or ecosystem level changes of importance.

Subcontractors must satisfy the following general criteria unless present scientific knowledge or contemporary scientific research practice dictate otherwise:

- a. data must be quantitative;
- b. statistical methods of analysis must be capable of detecting small changes in measured variables.
- c. well-established techniques of data collection and analysis must be used;

- d. taxa must be available for observation in reasonable numbers in the system area;
- e. naturally-occurring time-dependent and weather-dependent changes must be reasonably accounted for;
- f. biologic variables used as end-points must be sufficiently understood to ensure confident interpretation.
- g. unless otherwise approved by the IITRI program coordinator, blind scoring must be used in analyzing laboratory results;
- h. field studies shall be executed in a manner that produces minimal impact on the forest environment.

4.4 Experimental Design

Subcontractors must demonstrate that each study is designed and will be conducted to produce statistically meaningful results. Validity may be accounted for by numbers of samplings or observations, and/or population sizes.

4.5 Paired Plots

Subcontractors are encouraged to develop studies that maximize the use of paired plots and minimize the use of the same individuals or populations as both test and control subjects. It is recognized that the free-ranging behavior of some species may not permit separation of species and/or habitat into distinctive test and control groups.

Paired study plots that have essentially similar soil types, drainage, exposure to sunlight and vegetation type and density shall be used. Taxa of similar age and of the same class should be identified in analyses to minimize within-group variations.

4.6 Electromagnetic Exposure Levels

Test plots shall be selected at locations where electromagnetic fields produced by ELF antennas and ground terminals in soil near the earth's surface have the following nominal design values:

<u>Wisconsin Antenna System</u>	<u>Michigan Antenna System</u>
0.14 volt per meter (electric)	0.07 volt per meter (electric)
0.06 Gauss (magnetic)	0.03 Gauss (magnetic)
<u>Wisconsin Ground Terminals</u>	<u>Michigan Ground Terminals</u>
1.5 volt per meter (electric)	1.5 volt per meter (electric)
< 0.06 Gauss (magnetic)	< 0.03 Gauss (magnetic)

Electromagnetic field intensities near the intersections of antennas depend upon the relative phase between the currents in the antennas. They could be either higher or lower than nominal values by about a factor of two or less, and depend upon the operating mode of the system. Test locations at antenna intersections may therefore exhibit a range of time-dependent electromagnetic values. Anticipated system

operating frequencies range from about 40 to 80 Hz with MSK modulation. For proposal purposes, center frequencies \pm 4 Hz may be assumed (e.g., 76 \pm 4 Hz).

Overhead ELF antennas in both Wisconsin and in Michigan will produce electric fields of about 150 volts per meter in air near the surface of the earth. Unlike the longitudinal electric fields produced in soil, the fields in air dissipate rapidly as a function of distance in directions normal to the antenna, and are highest near the transmitter feed point.

Control plots shall be selected at locations where electric fields in soil near the surface of the earth produced by the ELF system are on the average at least one order of magnitude and preferably two orders of magnitude less than those at paired test plots. The same relationship shall exist for magnetic field components between test and control plots. Electric and magnetic fields in air and earth produced by other ELF sources (e.g., power lines) shall not differ by more than one order of magnitude between paired test and control plots, and at test plots should be at least one order of magnitude below the fields produced by the ELF system.

Electromagnetic field intensities shall be measured at study plots at intervals sufficient to characterize ELF exposure levels from extraneous sources. Field intensities shall be measured seasonally for studies in which habitats are sensitive to changes in the near-surface electrical conductivity of the earth at extremely low frequencies. Subcontractors may elect to measure ELF field intensity, or may request the data as furnished information. In the former case, measurement methods and equipment are subject to the approval of the IITRI program coordinator. Information will be supplied by IITRI on ELF System modulation characteristics necessary to determine appropriate measurement methods. IITRI reserves the right to verify subcontractor data by independent measurements.

Subcontractors should recognize that power lines may produce measurable ELF field intensities at harmonics of 60 Hz. Therefore, measurements should be made (at least initially) to account for these power harmonics as well as operating frequencies of the ELF Communications System.

4.7 Preconstruction Data Base

Antennas and ground terminals for the ELF Communications System in Wisconsin were installed in 1968-69. Installation of system components in Michigan will not be completed for several years. A preconstruction data base is not available for the Wisconsin system area. A preconstruction data base for the Michigan area is required for proposed work in that state. Available sources of data should be considered in assembling preconstruction data bases. Multiple test and control plots should be considered in Wisconsin to account for data limitations at that location.

5. SPECIFIC REQUIREMENTS

5.1 Ambient Monitoring

Ambient atmospheric, terrestrial and aquatic environmental conditions shall be monitored and recorded at or near each location selected for field ecology studies. Standard monitoring and reporting methods shall be used. Subcontractors must propose methodologies for monitoring ambient environmental factors pertinent to their proposed studies.

Important factors that characterize or which may affect soil and aquatic environments shall be monitored. Subcontractors shall investigate whether road salts, agricultural wastes or fertilizers, or industrial or community waste products are present in habitat used in these studies. Stream velocity, discharge, pH, specific conductance, alkalinity, silica, chlorides, total phosphate, nitrate, suspended solids, dissolved solids, total organic carbon, dissolved organic carbon, dissolved oxygen, discharge temperature and turbidity should be monitored. The frequency of measurements must be specified by subcontractors. Shading from nearby vegetation should be documented. Subcontractors are expected to augment this list as appropriate to their proposals.

Subcontractors are required to obtain information on atmospheric environmental conditions. Data may be obtained from established reporting sources, local observations or by direct measure (if appropriate). Temperature, precipitation, humidity, barometric pressure, solar radiation, cloud cover and wind conditions, and other phenomena shall be recorded. As noted above, subcontractors are expected to augment this list as appropriate to their proposals.

5.2 Soil Amoebae

Well-known soil amoebae shall be selected and species number determined by established techniques. Cell cycle analysis shall be performed. The efficiency of cropping bacteria shall be determined.

5.3 Soil and Litter Microfauna

Subcontractors shall obtain estimates of rates of breakdown of natural litter and examine the population dynamics of related species of organisms. Two contrasting ecosystems (e.g., hardwood and conifer forest settings) shall be investigated. Soil/litter characteristics which may be important to species composition, diversity and density shall be identified. The latter may include soil texture and moisture, temperature, pH, calcium, nitrate, ammonia, phosphate, organic carbon, exchangeable cations, chlorides and sulfates.

5.4 Earthworms

Subcontractors shall study earthworm population density and biomass. Soil characteristics identified above for soil microfauna studies shall be recorded. Earthworm casts from test and control plots should be compared with surrounding soil in terms of total nitrogen, organic carbon, exchangeable calcium, exchangeable

magnesium, available phosphorus, exchangeable potassium, organic matter, base capacity, pH and moisture equivalent.

Subcontractors shall make seasonal estimates of population patterns and functional capability of earthworms in test and control plots.

5.5 Herpetofauna

Species composition and density changes of reptiles and amphibians shall be determined by using standard techniques for herpetological surveys. Species shall be listed for distinctive habitat in the system area. Mark-recapture methods should be considered for determining population numbers. Trapping methods should be selected that ensure high survivorship. Species should be classified as common, uncommon or rare.

5.6 Small Mammal Biometric Survey

Subcontractors shall study small mammal species whose natural range is limited, whose abundance is high, and for which there is abundant literature on their ecology and techniques for study.

Population and range data shall be obtained within the ELF Communications System area and beyond the electromagnetic influence of the system. Electromagnetic characteristics noted above for paired plot studies generally apply except for constraints due to ranging of species.

In the event that important differences are noted in either population density or ranging characteristics between system-exposed and reference groups, subcontractors shall investigate possible causes of such changes. Parameters such as biomass, age profiles, fecundity and reproduction condition may be appropriate monitors.

5.7 Large Mammal Studies

Large mammal studies may not be useful in investigating whether ELF Communications System electromagnetic fields affect wildlife because of the free-ranging habitat of many large species. Their habitat generally encompasses ELF electromagnetic fields produced by numerous sources. While it may be possible to identify such sources, a cause-effect relationship probably cannot be established with one particular ELF source from among many sources and many field intensity levels. That is, exposure to ELF antenna electromagnetic fields cannot reliably be distinguished from exposure from other ELF sources. Nevertheless, large mammal studies are not necessarily excluded from this statement of work. If electromagnetic methods of monitoring species activity are proposed, subcontractors must demonstrate that tracking devices would not mask electromagnetic fields produced by the ELF Communications System.

The above notwithstanding, proposals are desired to collect and report data on habitat usage by deer. Information should be obtained on deer browse conditions, population distribution estimates, pellet counts,

location and condition of wintering yards, and hunter-kill records. Data available from state Departments of Natural Resources should be used.

5.8 Periphytic Algae

Subcontractors shall select aquatic environments for studying attached algae. The density, number of species and relative abundance of component populations shall be determined. A perennial aquatic moss may be used to determine cumulative effects over a long period of time. Diversity indices shall be developed to describe and compare periphytic community structure and relationships of component species to abiotic factors. The lowest positive taxon shall be identified. Algae production and appropriate physiological and biochemical indices should be determined.

5.9 Aquatic Insects

Subcontractors shall study insect life cycles and other phenomena to detect changes in benthic community structure and/or function. Representative species of chironomids, may flies, caddisflies and stoneflies shall be studied. Life cycle, body size, growth rate and population density characteristics should be analyzed.

5.10 Fish Studies

Subcontractors shall determine the fecundity, development, feeding and growth and behavioral habitat selection patterns of fish in aquatic environments within and distant from the electromagnetic influence of the ELF Communications System.

Two non-migratory fish species should be selected, one representing a species that feeds predominantly on benthic invertebrates, and the other representing a species that feeds predominantly on invertebrate drift and adult insects. Parasitic and pathogen infestation should be quantified as indicators of stress.

Subcontractors may also study a species of sport fish if one exists in the system area that exhibits predictable migratory or homing behavior. The relative numbers of fish in a spawning migration shall be determined at selected points. Counts may be made by using non-conductive weirs, but electronic devices cannot be used. Fixed plantings are permissible for these studies.

5.11 Pollinating Insects

Subcontractors shall study colonies of honeybees of known genetic stock in introduced hives close to and distant from ELF Communications System antennas and/or grounds and in reasonable proximity to abundant foraging plants. Behavior, reproduction and population dynamics shall be monitored. Orientation information on nectar sources and swarming activity shall be noted. Egg production, survival and adult

population size shall be studied. Comb size, shape and orientation; volume of honey production; and wax production shall be determined.

5.12 Nesting Birds and Migrating Birds in Flight

Subcontractors shall devise methods for studying behavior and populations of resident and migrant birds (including waterfowl) common to the region. Species should include at least one species of winter resident and one transient.

The abundance of selected migrating species shall be noted and their diversity of species described. Any changes from expected migratory behavior shall be reported.

Any abnormal nesting site tenacity expressed by birds near ELF antennas and grounds shall be reported. Any continuing tendency for young reared close to the antenna system to return to their natal area for breeding shall be noted. Behavior by transients shall be distinguished from that exhibited by resident species.

5.13 Herbaceous Plant Cover

Subcontractors shall study representative species of managed vegetation (annual crops and/or forage crops) and non-managed vegetation (successional communities and/or mature systems of understory components of forest communities). Developmental and life history stages of selected species should be analyzed throughout seasons of active growth and dispersal.

5.14 Trees

Deciduous and evergreen trees, including both fast-growing and slow-growing species, should be studied. Sample trees within paired plots shall be compared according to species, age, size and dominance class. Principal phenological events shall be recorded and analyzed. Physiological variables affecting growth and mortality may be appropriate monitors.

The productivity of commercially important trees in the region shall be studied. Plots selected for productivity studies shall be free of disease and insect infestation. Methods may include but are not restricted to collecting core samples and correlating annual ring width to climatological and environmental variables, followed by examination of core samples to detect deviations from expected patterns.

6. DELIVERABLES

6.1 Work Plan

Subcontractors shall prepare work plans identifying equipment development, plans, procedures and schedules for satisfying proposed tasks from this statement of work. The plan shall include a list of contributing professional personnel, and shall be submitted to the IITRI program coordinator within 30 days of subcontract award. Work plans shall be revised on a yearly basis or as otherwise necessary to account for changes in plans, staff, etc.

6.2 Monthly Reports

Subcontractors shall submit monthly status reports to the IITRI subcontract administrator with monthly invoices for services within 10 days of completing each month's work.

6.3 Annual Reports

Subcontractors shall prepare annual technical reports on each funded study included in this Program. The 1982 report shall be a summary of proposed work and is due on 30 October 1982. Subsequent yearly reports are due on 30 October of succeeding years.

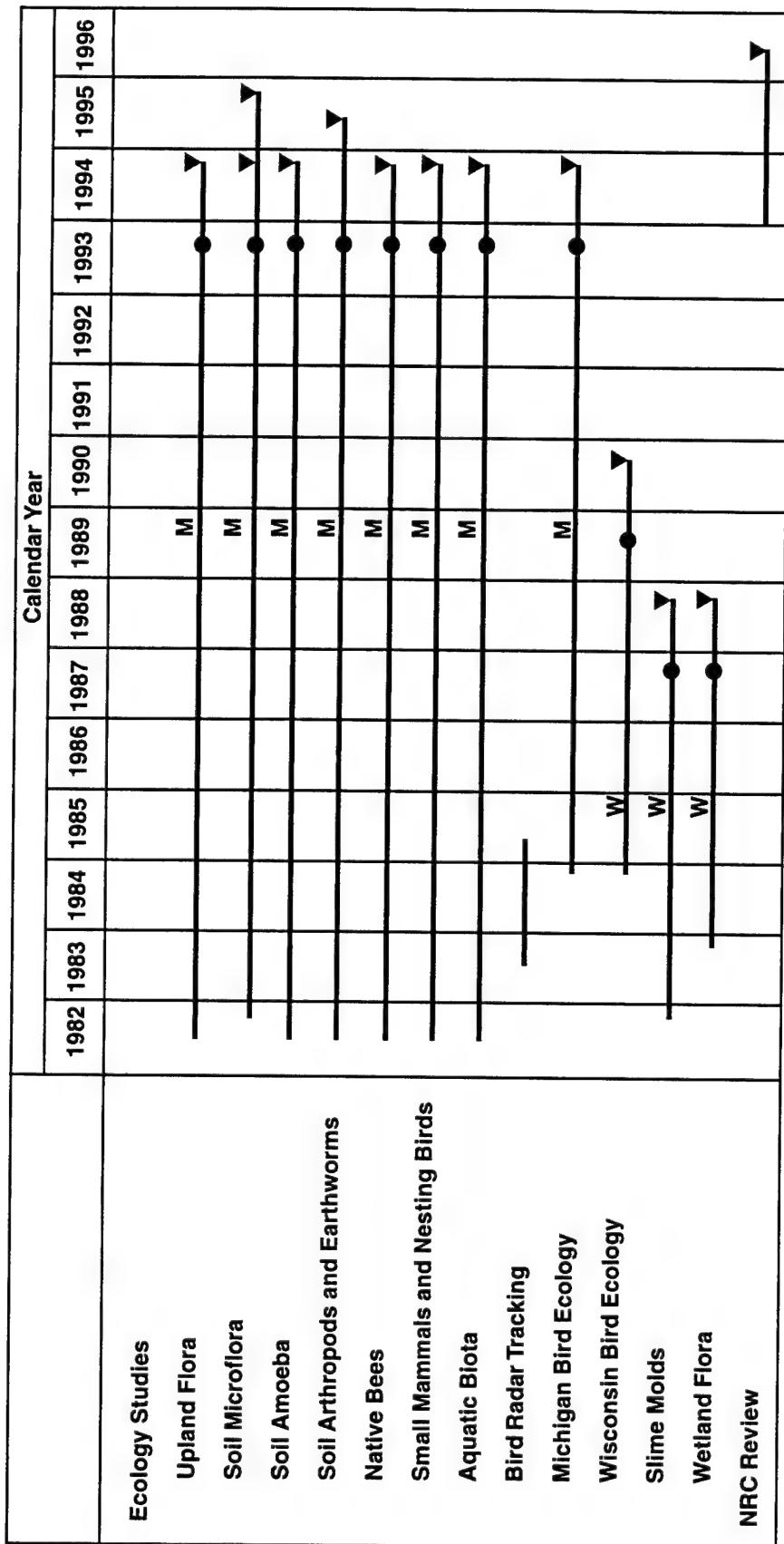
Voluminous reporting of data and procedures is not desired. The former should be summarized, and appropriate reference should be made to the work plan in the case of the latter. IITRI may exercise the option of receiving complete copies of data for independent analysis.

Each yearly report shall include a brief summary written to be understandable to the knowledgeable layman. The summary shall precede other material included in the report. One reproducible copy and 10 copies of each report shall be delivered.

Annual reports shall receive peer review. Subcontractors will select two reviewers, and IITRI will select two reviewers for each report. At least one reviewer selected by each organization shall represent Federal or state government not associated with the ELF Communications Program. Reviewers' comments on draft reports will be addressed by subcontractors in completing annual reports.

6.4 Yearly Symposium

Subcontractors shall participate in a yearly one-day symposium which will be open to the public. Work plans and study results shall be described. The symposium will be conducted in the fall of each year commencing in 1982. Locations will alternate between Wisconsin and Michigan with the 1982 symposium in Wisconsin.



Full Operational Capability – Michigan = M
 Full Operational Capability – Wisconsin = W
 End of Data Collection = ●
 Final Report = ▼

Figure B-1. ELF Ecological Monitoring: Program Summary.

APPENDIX C

VOLTAGE SPECTRA: SOUTH ANTENNA NRTF-CLAM LAKE

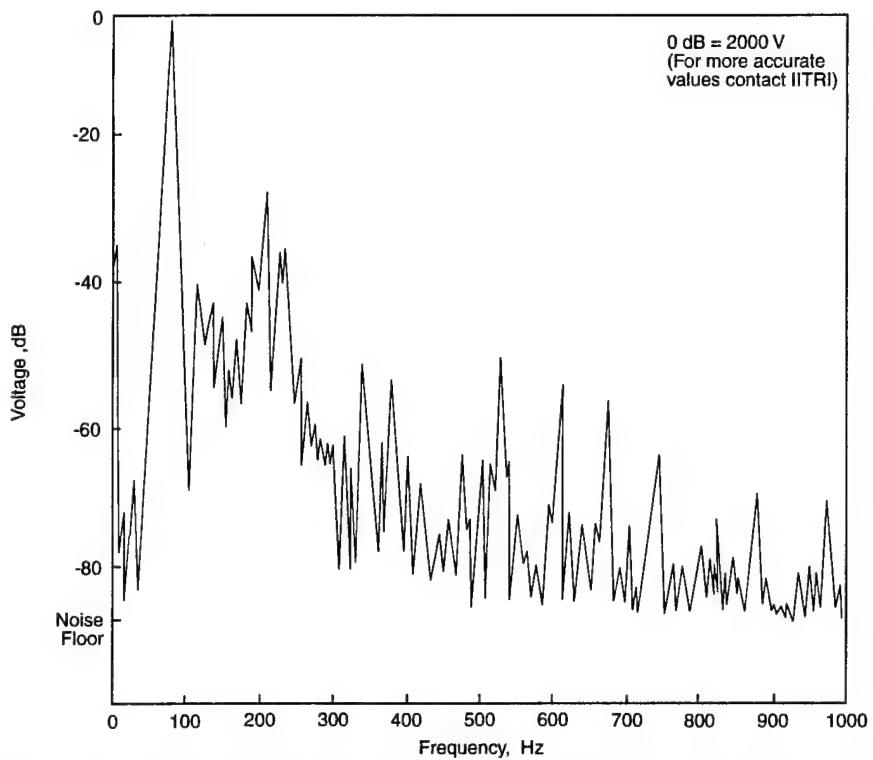


FIGURE C-1. VOLTAGE SPECTRUM (0-1000 Hz) FOR THE SOUTH ANTENNA OF THE WISCONSIN TRANSMITTER OPERATING AT 76 Hz, 300 AMPERES.

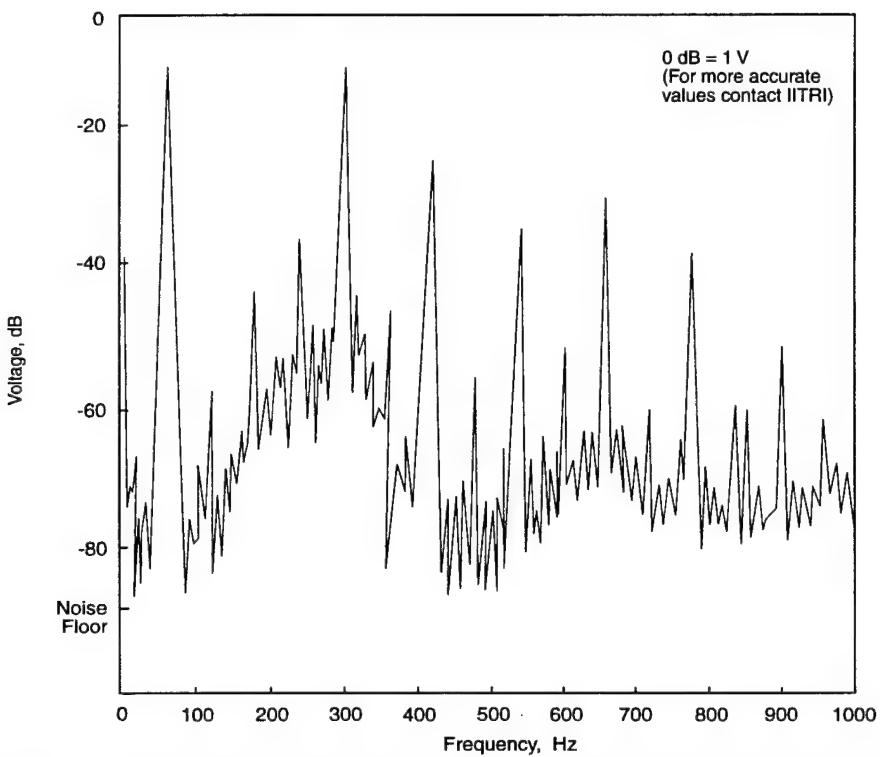


FIGURE C-2. VOLTAGE NOISE SPECTRUM (0-1000 Hz) FOR THE SOUTH ANTENNA OF THE WISCONSIN TRANSMITTER (BOTH ANTENNAS OFF).

APPENDIX D

**NON-EM ENVIRONMENTAL FACTORS MONITORED AT ELF
ECOLOGY SITES IN MICHIGAN AND WISCONSIN**

TABLE D-1. NON-EM ENVIRONMENTAL FACTORS MONITORED

Habitat/Location	Environmental Factor	No. of Sites	Years
Terrestrial/ NRTF-Republic, MI	Photosynthetically active radiation (PAR)	5	1986-1992
	Air temperature	7	1984-1993
	Soil and litter temperature	10	1984-1993
	Precipitation	7	1984-1993
	Soil and litter moisture	10	1984-1993
	Relative humidity	5	1987-1993
	pH	3	1984-1991
	Nutrients (N, P)	8	1984-1993
	Cations (Ca, K, Mg)	8	1984-1993
Wetland (peat bogs)/ NRTF-Clam Lake, WI	Water temperature	11	1984-1987
	Water table depth	11	1984-1987
	Color-dissolved organic carbon	11	1984-1987
	pH	11	1984-1987
	Conductivity	11	1984-1987
	Cations (Ca, K, Mg)	11	1984-1987
Aquatic (Ford River)/ NRTF-Republic, MI	PAR	2	1983-1993
	Air temperature	2	1983-1993
	Water temperature	2	1983-1993
	Discharge (velocity)	2	1983-1993
	Precipitation	2	1983-1993
	Turbidity	2	1983-1993
	pH	2	1983-1993
	Conductivity	2	1983-1993
	Alkalinity	2	1983-1993
	Nutrients (N, P, Si)	2	1983-1993

Note: Meteorological data from NOAA Stations at Crystal City and Iron Mountain, Michigan, were also used.

